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SUMMARY

An exploratory study has been made to examine the effect of secondary tasks in determining permissible time delays in visual-motion simulation of a pursuit tracking task. This study uses a single subject, a single set of aircraft handling qualities, and a single motion condition in tracking a target aircraft that oscillates sinusoidally in altitude. In addition to the basic simulator delays the results indicate that the permissible time delay is about 250 msec for either a tapping task, an adding task, or an audio task and is approximately 125 msec less than when no secondary task is involved. The magnitudes of the primary task performance measures, however, differ only for the tapping task. A power spectral density analysis basically confirms the results obtained by comparing the root-mean-square performance measures. For all three secondary tasks, the total pilot workload was quite high.

INTRODUCTION

With the increased use of flight simulators, the time delays in visual and motion cues caused by the sampling rates used in digital computation, by the inertias in the image and motion generating systems, and by the computation time required in producing computer generated images become increasingly important. An experimental investigation has been conducted to determine the amount of time delay that can be tolerated in the visual and motion feedback loops of a simulated pursuit tracking task. Because many factors influence the tolerable time delay, the investigation was presented in four reports. The initial report (ref. 1) was primarily concerned with the effects of airplane handling qualities and employed two subjects and a fixed-base simulator to examine 17 aircraft configurations having different longitudinal short-period characteristics. The second report (ref. 2) showed that the incorporation of motion cues enabled the subjects to maintain a given level of performance for longer time delays. The second report was primarily concerned with motion cues and subject effects and employed three aircraft configurations, four motion conditions, and four subjects. Each of these factors had a significant effect on pilot performance. Both references 1 and 2, however, required the subject to perform a secondary task in order to increase total pilot workload so that no reserve capability was available when the difficulty of the primary task was altered. The secondary task employed was a tapping task that involved visual interruption of the tracking task and, hence, interfered with the primary task. Because there was no way to control performance of the tapping task, each of the subjects used the secondary task in a different manner. The most significant difference was the research pilot's extreme hesitancy to look away from the primary task to attend to the tapping task. These differences in secondary task performance were believed to contribute greatly to the significant differences between the subjects' performances of the primary task. Consequently, an alternate secondary task (ref. 3) was used in which the subjects were required to control an audio signal driven with the output of an unstable first-order linear system. Reference 3 employed the basic aircraft of reference 2, full motion and

no motion, and two subjects. When the audio task was used, the error magnitude and the breakpoint location of the total tracking error and the control inputs were essentially the same under motion-base conditions for both the primary subject and the research pilot. It was concluded that the differences in subject performance of the primary task noted in reference 2 were primarily associated with the visual interruption imposed by the tapping task and were not due to a basic difference in subjects.

The current report is an exploratory study that uses a single subject, the basic aircraft, and full-motion conditions to see whether the secondary task is a significant factor in determining permissible time delays in visual-motion simulation of a pursuit tracking task. In addition to the primarily visual (tapping) and aural tasks previously studied, this report adds a mental (adding) task that requires no manual coordination. As a basis of comparison, this report also includes the condition of no secondary task.

In addition to the statistical analysis of the performance measures used in references 2 and 3, this report includes a power spectral density (PSD) analysis of the pilot inputs and system outputs to determine whether there were changes in frequency content due to time delays, secondary tasks, or motion conditions.

SYMBOLS

a	acceleration caused by aerodynamic forces, m/sec^2
F	statistical quantity associated with F distribution
F_Y	side force, N
g	gravitational acceleration, $1g = 9.80665$ m/sec^2
I	moment of inertia, kg-m^2
K_n	gains used in motion-base drive equations ($n = 0$ to 18)
L	lift force, N
L_o	$= \dfrac{\text{Trim lift}}{mV_{x,o}}$, per sec
L_p	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial p}$, per sec
L_r	$= \dfrac{1}{I_X}\dfrac{\partial M_X}{\partial r}$, per sec

L_α $= \dfrac{1}{mV_{x,o}} \dfrac{\partial L}{\partial \alpha}$, per sec-rad

L_β $= \dfrac{1}{I_X} \dfrac{\partial M_X}{\partial \beta}$, per sec^2

L_{δ_a} $= \dfrac{1}{I_X} \dfrac{\partial M_X}{\partial \delta_a}$, per sec^2

ℓ_j, m_j, n_j direction cosines ($j = 1, 2, 3$)

M_q $= \dfrac{1}{I_Y} \dfrac{\partial M_Y}{\partial q}$, per sec

M_X rolling moment, N-m

M_Y pitching moment, N-m

M_Z yawing moment, N-m

M_α $= \dfrac{1}{I_Y} \dfrac{\partial M_Y}{\partial \alpha}$, per sec^2

M_{δ_e} $= \dfrac{1}{I_Y} \dfrac{\partial M_Y}{\partial \delta_e}$, per sec^2

m aircraft mass, kg

N_p $= \dfrac{1}{I_Z} \dfrac{\partial M_Z}{\partial p}$, per sec

N_r $= \dfrac{1}{I_Z} \dfrac{\partial M_Z}{\partial r}$, per sec

N_β $= \dfrac{1}{I_Z} \dfrac{\partial M_Z}{\partial \beta}$, per sec^2

N_{δ_a} $= \dfrac{1}{I_Z} \dfrac{\partial M_Z}{\partial \delta_a}$, per sec^2

N_{δ_r} $= \frac{1}{I_Z}\frac{\partial M_Z}{\partial \delta_r}$, per sec^2

p angular rate around aircraft longitudinal body axis, rad/sec

p_K roll motion drive signal before compensation, rad/sec

q angular rate around aircraft lateral body axis, rad/sec

r angular rate around aircraft normal body axis, rad/sec

t( ) statistical quantity of "t"-test of student's t distribution; parentheses designate particular factor considered

u,v,w aircraft velocities along longitudinal, lateral, and normal body axes, respectively, m/sec

V_x,V_y,V_z components of aircraft velocity relative to inertial space, m/sec

Y_β $= \frac{1}{mV_{x,o}}\frac{\partial F_Y}{\partial \beta}$, per sec-rad

y_c,z_c lateral and vertical drive commands, respectively, for motion base, m

y_K lateral motion drive signal before compensation, m

z_K vertical motion drive signal before compensation, m

α change in angle of attack from trim, rad

β sideslip angle, rad

δ_a aileron deflection, rad

δ_e elevator deflection, rad

δ_r rudder deflection, rad

δ_s audio task thumb-wheel deflection, volts (scale factor is 22.9 deg/volt)

ε_h horizontal (lateral) tracking error, m

ε_s audio task tracking error, volts (scale factor is 460 Hz/volt)

ε_v vertical tracking error, m

θ_c, φ_c pitch and roll drive commands for motion base, rad

$\bar{\sigma}$ unbiased estimate of standard deviation

ψ, θ, φ Euler angles, rad

ω_{δ_s} audio task thumb-wheel input frequency, Hz

Subscripts:

o indicates initial condition

X,Y,Z denote aircraft body axes

Abbreviations:

ANOV analysis of variance

DAC digital-to-analog converter

PSD power spectral density

rms root mean square

VMS visual-motion simulator

A dot over a quantity indicates a derivative with respect to time. A bar over a symbol indicates the arithmetic mean of rms values for all runs having identical test conditions.

DESCRIPTION OF APPARATUS

The tests were performed in the Langley visual-motion simulator (VMS) which is a hydraulically operated, six-legged synergistic motion base. (See fig. 1.) Six computed leg positions were used to drive the motion base. The computed actuator extensions were passed from the computer to the motion base through digital-to-analog converters (DAC) every 31.25 msec. To eliminate the stairstepping in this output and provide smooth continuous signals for driving the motion base, the DAC outputs were passed through notch filters on the hardware. Filter characteristics are given in reference 4, and transformations used to compute the leg extensions are given in reference 5. References 4 and 6 give the performance limits of the VMS. For the present report, the VMS was used as both a fixed-base and a motion-base simulator. The motion condition used in this report provides motion in four degrees of freedom: roll, pitch, heave, and sway. There was no yaw motion because reference 1 indicated that the rudder pedals were never used, and airplane yawing due to aileron deflection provided cues below threshold for the tasks. The roll motion and the sway motion were employed in a coordinated manner (ref. 7) primarily in an attempt to remove the

false cue caused by the gravity component during the performance of a coordinated turn in a simulator. The longitudinal distance between the two aircraft was held constant throughout the study, and reference 1 indicated that only small pitch excursions were used. Consequently, coordination (ref. 8) between pitch motion and longitudinal motion was not necessary, and longitudinal motion was not included. The pitch signals (ref. 1) were so small that neither washout nor scaling was required. The heave motion employed second-order linear filtering with the washout parameters used in references 2 and 3. The motion-base drive equations are presented in table I.

The pilot's compartment was representative of a two-man cockpit (fig. 2). Although the panel instruments were illuminated, they were not operational and were not used by the pilot subjects. Visual cues (target aircraft) were generated by a small model and closed-circuit television. The model was mounted in a two-axis support, and rotated in pitch and yaw in response to the relative equations of motion of the two aircraft so that the subject saw the proper aspect of the target. Target aircraft roll was accomplished electronically. Elevation and azimuth changes of the target aircraft in the display were obtained by repositioning the television raster electronically. The repositioning was accomplished by using scaled voltages to represent angles of deflection in elevation and azimuth. This technique eliminated unwanted delays in visual-scene presentation; such delays occur when electromechanical systems (involving mirrors, gears, and electric motors) are used to obtain elevation and azimuth positions. The image was displayed by use of a closed-circuit television screen (fig. 3) with an infinity optics mirror. The horizon was also projected on the screen. A reticle (two crossed lines) was projected on the center of the screen to represent sights on the aircraft flown by the subject.

The subject maneuvered his aircraft by using a two-axis finger-tip pencil controller of the force-stick type; this device controlled rotations about the aircraft pitch and roll axes. Force-stick characteristics are given in figure 4. The controller is shown in the photograph of figure 2. The equations of motion of the pursuing aircraft are given in the appendix. All equations of the simulation, except those for the audio task, were solved on a digital computer. The digital outputs were then converted to analog signals to drive the visual-scene and motion generation equipment. The Langley Research Center hardware for computer signal processing from analog to digital and back to analog can be represented mathematically as a prefilter, a computational delay, and a zero-order hold. The prefilter attenuates the analog input signal high-frequency components to suppress "aliasing" during the analog-to-digital conversion. The computational delay is the delay associated with the input, the processing, and the output of a signal through the computer. Finally, a zero-order hold adds one-half the computing interval caused by the sample-hold characteristics. This last delay represents an average value for that portion of the equipment which includes the DAC. For the prefilter setting of this study, the described hardware characteristics create an average time delay from input to output of 1.5 times the update interval. This delay has an average value of about 47 msec which becomes part of the delay in the visual-scene presentation. The delay due to the scene generation equipment for elevation and azimuth line-of-sight angles to the target and the delay due to the television display of the scene to the subject were small. Motion cue presentation also has this 47-msec time delay. In addition, the motion-base mechanical drive

system has those time lags after compensation described in reference 4. These motion-base lags are a function of frequency. The lags expressed as an equivalent time delay were on the order of 50 msec when based on the pursuit aircraft longitudinal short-period frequency of 2.83 rad/sec. (See table X of ref. 2.)

PILOT TASK

The primary task in the present study, as in references 1, 2, and 3, was to track a target aircraft that was performing a sinusoidal oscillation in the vertical plane with an amplitude of ±30.48 m and a frequency of 0.21 rad/sec (0.03 Hz). Precognitive control related to the sinusoidal nature of the target motion should be impossible at frequencies below 0.63 rad/sec (0.10 Hz) (ref. 8). The pursuit aircraft automatically maintained a 182.88-m separation distance behind the target aircraft. The pursuit aircraft could maneuver in the remaining five degrees of freedom and was controlled through the use of a two-axis finger-tip controller.

Data using three separate secondary tasks were analyzed in this study. The tapping task (refs. 1 and 2) required the subject to alternately tap a stylus against two metal strips inlaid in a wooden board strapped to the subject's left leg. The audio task (ref. 3) required the subject to maintain an audio signal at 1200 Hz using a thumb wheel with his left hand. The audio signal was driven with the output of an unstable first-order linear system with a 1/2-sec time constant. The mental task required the subject to add sets of three single-digit numbers that were given to him verbally. The sum of the three digits for each set was always greater than 10 but less than 20. The sets of numbers were given as rapidly as possible throughout each 2-min run and the number of correct and incorrect responses was recorded. The mental task did not require the manual coordination necessary for performance of the tapping and audio tasks.

TEST PROGRAM

The basic aircraft of reference 2 is defined by the parameters listed in table II and was used throughout this investigation. In general, two factors were considered in the study: time delays and secondary tasks. Time delays in visual-motion cue presentation were varied in multiples of 31.25 msec because that was the update interval of the digital computer used in the study. The data were collected for 0, 4, 8, 12, and 16 units of delay as was done in references 2 and 3. The three secondary tasks described in the previous section were employed in the study, and pilot performance was measured for an interval of 2 min for each run. Ten runs were performed at each time delay for each secondary task under motion-base conditions. As a basis for evaluating primary task performance, a series of 10 simulated flights was also performed at each time delay without any secondary task.

The statistical data for the tapping task were taken from reference 2 and are reproduced in table III for reference. The statistical data for the audio task were taken from reference 3 and are presented in table IV for reference. The statistical data for the adding task and for no secondary task are presented

in tables V and VI, respectively. The data for the three secondary tasks and the data for no secondary task were examined statistically to determine whether secondary tasks or time delays were significant factors.

In addition, PSD data were obtained for individual flights performed at 0 and 16 units of delay for each of the three secondary tasks and for no secondary task under both motion-base and fixed-base conditions to examine the frequency content of the pilot's performance.

RESULTS AND DISCUSSION

The tracking task performance measures used in the current report and in references 1 and 2 include the rms values (over the 2-min flight) of the vertical and lateral displacements of the center of gravity of the target aircraft from that of the pursuit aircraft. The rms values of the aileron and elevator control inputs were also collected. The primary performance measure, however, was the total tracking error which is the arithmetic sum of the rms vertical and lateral center-of-gravity displacements for each run.

Statistical Analysis

Each performance measure was examined statistically as were the thumb-wheel input and the tracking error when the audio task was used. An analysis of variance (ANOV) was conducted to determine whether any of the experimental factors (ref. 9) or interactions of the factors were significant. In the ANOV in table VII, four secondary tasks were considered; no secondary task was considered as a zero level secondary task. The ANOV indicates that both time delay and secondary task are significant factors (at the 5-percent level of significance) for all performance measures. In addition, interaction between time delay and secondary task is a significant factor for the total error which is the primary performance measure. Since the ANOV indicates that both time delay and secondary task are significant factors, t-tests were performed to determine which levels of each factor differed significantly from the control level of each factor (zero time delay and no secondary task, respectively). It should be noted that the standard error used in the t-tests for the time delays was based on data pooled over all time delays for a given secondary task. In like manner, the standard error used in the t-tests for secondary tasks was based on data pooled over all secondary tasks for a given time delay.

Time-delay effects.- The rms performance measures for the tapping tasks are plotted as functions of time delay in figure 5. Each point represents the mean of 10 data runs, and the fairing is used to help visualize the statistical significance of the time delays. If the second data point, at four units of time delay, is not significantly different from the zero delay point at the 5-percent level, the line continues at the original value. For each larger time delay, the line continues until the 5-percent significance level is reached, at which time the line is drawn to the data point. The main purpose of the fairing is to show the break point at which the performance begins to degrade. Consequently, the lines are not extended beyond the first significantly different data point even though the t-test was applied at all time

delays. Increasing time delay generally causes a degradation in pilot performance. The break point in total error, which is the primary performance measure, occurs at 8 units of delay. It should be noted that the tapping tasks were used early in the investigation and the pilot's performance was influenced by the relatively poor lateral trim setup that existed at that time. The poor lateral trim had very little effect (ref. 2) on the location of the time delay break point but did affect the level of the pilots performance. The primary performance measure, the total tracking error, was approximately 20 percent larger than it should have been (ref. 2), but the vertical error component was not significantly affected.

The rms values of the performance measures when the audio task is used as the secondary task are presented in figure 6. The audio task provides statistical evidence that the subject is fully occupied at all times and is a more acceptable secondary task, from a subject's standpoint, than the tapping task. (See ref. 3.) The break point in the primary performance measure, the total tracking error, occurs at 8 units of delay as was the case when the tapping task was employed.

The rms values of the performance measures when the adding task is used are presented in figure 7. The performance of the adding task (number of correct responses) shows no degradation as time delays in the primary task increase. However, the subject stated that the adding task resulted in a very high total workload. The subject's tracking performance when the adding task is used is quite similar to that when the audio task is used. In particular, the total tracking error again has its break point at 8 units of delay. Thus, within the resolution of the data, the break point in time delay is the same for each of the secondary tasks. This common break point for all secondary tasks is not totally expected because the magnitude of the total tracking error is significantly larger when the tapping task is used. Also, the subject believed the tapping task was a less suitable secondary task than the audio or adding task.

The rms values of the performance measures when no secondary task is used are presented in figure 8 for comparison purposes. The primary difference in the subject's performance when no secondary task is performed is that a larger time delay, 12 units, can be tolerated before the total tracking error degrades significantly.

Secondary task effects.- The ANOV indicated that secondary task is a significant factor (at the 5-percent level) for all performance measures. Further t-tests, using the no secondary task condition as the control, indicate that the differences in secondary tasks stem from the tapping task being significantly different from the other tasks. At the 5-percent level, the adding and audio tasks do not result in tracking task performances that are different from the performances without a secondary task. The subject considered each of the three secondary tasks to provide a very high workload. However, the tapping task was subjectively the least satisfactory for use with a visual tracking task because it required the subject to look away from the primary task. The adding task had the advantage of requiring no manual coordination and involved a minimum of training. The audio task required considerable training but was the only task structured to yield statistical evidence of high workload. (See ref. 3.)

Power Spectral Densities

It was believed that a PSD analysis of the control inputs and system outputs might show a change in frequency content when secondary tasks or time delays were varied. The acceleration components were examined because the pilots preferred motion-base to fixed-base conditions even when the rms performance measures were not very different. Each 2-min run was evaluated every 31.25 msec so that aliasing would not be a problem at frequencies expected for piloted simulation. The PSD analysis used 1024 lag values in conjunction with a sample size of 3840 to yield an equivalent resolution band width of 0.03 and a normalized standard error of 0.5.

Typical runs for each secondary task under motion-base conditions at 0 and 16 units of delay have been examined for their spectral content and are presented in figures 9 and 10, respectively. The corresponding runs under fixed-base conditions are presented in figures 11 and 12. The audio task data, the adding task data, and the no secondary task data have PSD's that are essentially the same for all parameters considered; only the tapping task data are different. With the tapping task, the pilot not only uses more power at approximately 0.2 Hz, but also employs a larger amount of power at higher frequencies (for example, figs. 9(a) and 11(a)) than with the other secondary tasks in an attempt to obtain small tracking errors. The primary effect of time delay is an increase in power as time delay increases. (For example, see figs. 11(a) and 12(a).) The effect of motion on the PSD results is generally fairly small. The PSD analysis shows no frequency effect of secondary tasks or time delays above 0.1 Hz and the 2-min runs yield insufficient data for high confidence below 0.1 Hz.

CONCLUDING REMARKS

Previous studies in this series have identified subjects, pursuit aircraft, and motion conditions as significant factors effecting permissible time delay in visual-motion simulation of a pursuit tracking task. The present exploratory study uses a single subject, a set of aircraft handling qualities, and a motion condition to determine whether secondary tasks have a significant effect on permissible time delay. The secondary tasks considered include a mental task in addition to the tapping and audio tasks previously studied and include the condition of no secondary task as a basis for comparison. The subject operates at a high total workload with each of the secondary tasks. However, the tapping task is subjectively the least satisfactory because it involves a visual interruption of the primary tracking task. The mental (adding) task has the advantage of requiring no manual coordination and thus minimizes training. The audio task requires considerable training but is the only task considered that is structured to yield statistical evidence of high workload.

A statistical analysis of the tracking data indicates that performance degradation due to time delay is the same for the three secondary tasks considered. The tapping task, the adding task, and the audio tasks all result in a total tracking error for the primary task that degrades at about 250 msec of time delay. When no secondary task is required the tracking error degrades at about 375 msec of time delay. The level of tracking performance, across all

time delays, differs at the 5-percent level of significance only when the tapping task is used. The subject, however, believed the total task to be quite demanding when any of the secondary tasks were used, and found that the primary task alone was fairly easy. A power spectral density analysis basically confirms the statistical analysis.

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APPENDIX

EQUATIONS OF MOTION

The linearized equations of motion used in this study for the pursuing aircraft are written about the aircraft body axes and are:

$$a_X = 0 \tag{A1}$$

$$a_Y = Y_\beta \beta V_{x,o} \tag{A2}$$

$$a_Z = -(L_\alpha \alpha + L_o) V_{x,o} \tag{A3}$$

$$\dot{p} = L_p p + L_\beta \beta + L_r r + L_{\delta_a} \delta_a \tag{A4}$$

$$\dot{q} = M_\alpha \alpha + M_q q + M_{\delta_e} \delta_e \tag{A5}$$

$$\dot{r} = N_r r + N_\beta \beta + N_p p + N_{\delta_r} \delta_r \tag{A6}$$

In equations (A2) and (A3)

$$\alpha = \tan^{-1} \frac{w}{u}$$

$$\beta = \sin^{-1} \frac{v}{V}$$

$$V = (V_x^2 + V_y^2 + V_z^2)^{1/2}$$

and

$$u = \ell_1 V_x + \ell_2 V_y + \ell_3 V_z$$

$$v = m_1 V_x + m_2 V_y + m_3 V_z$$

$$w = n_1 V_x + n_2 V_y + n_3 V_z$$

APPENDIX

Aircraft orientation and velocity relative to inertial space are required to generate the proper position of the target relative to the pursuer (for display purposes). The orientation of the pursuer in space is specified by Euler angles. These angles are determined from body angular rates by

$$\dot{\varphi} = p + q \sin \varphi \tan \theta + r \cos \varphi \tan \theta$$

$$\dot{\theta} = q \cos \varphi - r \sin \varphi$$

$$\dot{\psi} = (r \cos \varphi + q \sin \phi)\frac{1}{\cos \theta}$$

Inertial accelerations are given by

$$\dot{V}_X = \ell_1 a_X + m_1 a_Y + n_1 a_Z$$

$$\dot{V}_Y = \ell_2 a_X + m_2 a_Y + n_2 a_Z$$

$$\dot{V}_Z = \ell_3 a_X + m_3 a_Y + n_3 a_Z + g$$

Direction cosines are defined as follows:

$$\ell_1 = \cos \psi \cos \theta$$

$$\ell_2 = \sin \psi \cos \theta$$

$$\ell_3 = -\sin \theta$$

$$m_1 = \cos \psi \sin \theta \sin \varphi - \sin \psi \cos \varphi$$

$$m_2 = \sin \psi \sin \theta \sin \varphi + \cos \psi \cos \varphi$$

$$m_3 = \cos \theta \sin \varphi$$

$$n_1 = \cos \psi \sin \theta \cos \varphi + \sin \psi \sin \varphi$$

$$n_2 = \sin\psi \sin\theta \cos\varphi - \cos\psi \sin\varphi$$

$$n_3 = \cos\theta \cos\varphi$$

Initial conditions were $V_{x,o} = 304.8$ m/sec; $V_{y,o} = V_{z,o} = 0$; $\psi_o = \theta_o = \varphi_o = 0$; and $p_o = q_o = r_o = 0$.

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TABLE I.- MOTION-BASE DRIVE EQUATIONS AND GAIN VALUES USED

(a) Motion-base drive equations

$$\theta_c = \theta + K_0\dot{\theta}$$

$$\dot{p}_K = K_1 p - K_2 p_K - K_3 a_Y$$

$$\ddot{y}_K = K_4 a_Y + K_5 p_K - K_6 \dot{y}_K - K_7 y_K$$

$$\varphi_c = K_8 \varphi + K_9 p_K + K_{10} \dot{p}_K + K_{11} \dot{\varphi}$$

$$y_c = y_K + K_{12} \dot{y}_K + K_{13} \ddot{y}_K$$

$$\ddot{z}_K = K_{14} \dot{V}_z - K_{15} \dot{z}_K - K_{16} z_K$$

$$z_c = z_K + K_{17} \dot{z}_K + K_{18} \ddot{z}_K$$

(b) Gain values

Gain	Motion case
$^aK_0$	0.15
K_1	.50
K_2	.322
K_3	.01
K_4	1.00
K_5	32.2
K_6	1.134
K_7	.67
K_8	0
K_9	1.0
$^aK_{10}$	.15
$^aK_{11}$	0
$^aK_{12}$	.15
$^aK_{13}$	.007
K_{14}	.15
K_{15}	2.02
K_{16}	2.01
$^aK_{17}$	.1333
$^aK_{18}$	.007

[a]Hardware compensation parameters.

TABLE II.- PARAMETERS OF "BASIC" AIRCRAFT

[Data from ref. 2]

Parameter	Value
L_α	2.0
L_o	.0322
M_α	6.0
M_q	-7.0
M_{δ_e}	-10.0
L_β	-42.14
L_p	-2.74
L_r	2.058
N_β	5.544
N_p	.0148
N_r	-.2782
Y_β	-.1589
L_{δ_a}	-10.0
N_{δ_a}	0
N_{δ_r}	-10.0

TABLE III.- SUMMARY OF DATA FOR TAPPING TASK

[From ref. 2]

(a) Total error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	7.175	6.806	7.004	8.217	7.977
	7.446	6.379	6.764	7.148	10.394
	6.187	7.105	6.733	8.236	10.747
	7.330	7.081	5.297	7.714	8.498
	5.276	5.901	6.069	11.421	13.219
	5.666	5.566	6.130	10.144	6.837
	6.215	6.779	6.709	8.220	7.928
	7.337	7.132	6.608	8.501	9.991
	7.772	8.867	7.693	7.958	7.443
	5.718	7.093	8.915	7.724	9.824
$\bar{\epsilon}_v + \bar{\epsilon}_h$	6.612	6.871	6.792	8.529	9.286
$\bar{\sigma}$	.896	.888	.978	1.282	1.920
t(time delay)	Control	.46	.39	[b]3.42	[b]4.77

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE III.- Continued

(b) Vertical error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	4.543	4.415	5.236	5.273	5.724
	4.659	4.514	4.812	5.046	6.499
	4.425	5.414	5.161	6.040	7.495
	4.794	4.882	3.589	5.463	5.886
	4.034	3.702	4.662	6.628	6.211
	3.911	3.731	3.845	6.544	5.028
	4.596	3.828	4.451	4.953	4.766
	4.520	4.784	4.427	5.219	5.664
	4.516	4.818	4.617	4.729	4.524
	4.172	4.834	5.878	5.519	6.742
$\bar{\epsilon}_v$	4.417	4.492	4.668	5.541	5.854
σ	.285	.574	.667	.656	.926
t(time delay)	Control	.26	.85	[b]3.84	[b]4.91

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE III.- Continued

(c) Horizontal error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	2.633	2.391	1.770	2.633	2.252
	2.788	1.865	1.952	2.102	3.894
	1.764	1.692	1.574	2.195	3.254
	2.536	2.197	1.729	2.251	2.612
	1.241	2.198	1.406	4.794	7.007
	1.754	1.836	2.284	3.599	1.809
	1.618	2.952	2.257	3.268	3.163
	2.816	2.349	2.183	3.281	4.327
	3.256	4.049	3.077	3.229	2.924
	1.546	2.258	3.040	2.206	3.082
$\bar{\epsilon}_h$	2.195	2.379	2.127	2.956	3.432
σ	.684	.686	.570	.853	1.452
t(time delay)	Control	.45	.17	1.88	[b]3.06

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE III.- Continued

(d) Aileron deflection (× 10^2), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	1.328	1.732	1.758	2.404	2.468
	1.563	1.207	1.583	2.497	2.470
	1.441	1.461	1.842	3.099	2.799
	1.618	1.573	1.886	2.197	2.386
	1.108	1.723	1.424	2.253	3.022
	1.213	1.417	1.951	2.281	2.659
	1.977	1.844	2.253	2.634	2.472
	2.608	3.002	2.826	2.404	2.727
	2.708	2.955	2.516	1.793	1.477
	1.290	1.752	3.070	1.184	1.415
$\bar{\delta}_a$	1.685	1.867	2.111	2.275	2.389
$\bar{\sigma}$	.568	.616	.542	.508	.533
t(time delay)	Control	.73	1.72	[b]2.38	[b]2.84

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE III.- Concluded

(e) Elevator deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.525	0.634	0.583	0.710	0.602
	.566	.632	.580	.632	.540
	.535	.651	.644	.599	.642
	.712	.725	.622	.626	.610
	.601	.712	.782	.722	.600
	.568	.649	.664	.592	.637
	.603	.609	.638	.585	.629
	.675	.665	.712	.606	.663
	.604	.694	.684	.596	.514
	.454	.553	.684	.566	.521
$\bar{\delta}_e$	0.584	0.653	0.659	0.623	0.596
σ	.074	.051	.062	.052	.053
t (time delay)	Control	[b]2.59	[b]2.85	1.49	.43

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- SUMMARY OF DATA FOR AUDIO TASK

[Data from ref. 3]

(a) Total error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	3.405	3.432	3.936	4.091	3.880
	3.834	3.672	3.613	4.462	4.907
	3.549	3.675	3.777	3.913	4.481
	3.432	3.686	3.519	3.317	4.255
	3.329	3.328	3.417	4.077	4.303
	3.460	3.519	3.505	3.546	3.476
	3.243	3.301	3.492	3.621	4.487
	3.387	3.492	3.512	3.669	3.933
	3.255	3.262	3.357	3.538	3.970
	3.449	3.338	3.533	3.328	3.798
$\bar{\epsilon}_v + \bar{\epsilon}_h$	3.434	3.470	3.565	3.756	4.150
$\bar{\sigma}$	.170	.165	.172	.370	.417
t(time delay)	Control	.29	1.04	[b]2.56	[b]5.69

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(b) Vertical error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	2.969	2.902	2.952	3.230	3.154
	3.102	2.931	2.934	3.425	3.644
	2.869	2.940	3.058	2.915	3.472
	2.788	2.820	2.835	2.813	3.282
	2.839	2.783	2.907	2.882	3.325
	2.913	2.882	2.911	2.922	2.922
	2.711	2.675	2.897	2.890	3.420
	2.757	2.854	2.791	2.990	2.962
	2.663	2.782	2.740	2.709	3.211
	2.794	2.759	2.795	2.738	3.049
$\bar{\epsilon}_V$	2.840	2.833	2.882	2.951	3.234
$\bar{\sigma}$	.130	.084	.094	.221	.248
t(time delay)	Control	.10	.55	1.47	[b]5.21

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(c) Horizontal error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.435	0.529	0.986	0.861	0.726
	.732	.741	.679	1.037	1.263
	.681	.735	.719	.999	1.010
	.644	.866	.684	.504	.973
	.490	.544	.509	1.194	.978
	.547	.638	.594	.624	.654
	.532	.626	.595	.731	1.068
	.630	.638	.720	.679	.971
	.592	.480	.617	.830	.758
	.655	.579	.738	.590	.749
$\bar{\epsilon}_h$	0.594	0.638	0.684	0.805	0.915
σ	.092	.116	.128	.221	.189
t (time delay)	Control	.63	1.29	[b]3.01	[b]4.58

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(d) Aileron deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	1.371	1.281	1.437	1.531	1.636
	1.235	1.144	1.183	1.167	1.596
	1.288	1.050	1.095	1.794	1.622
	1.259	1.423	2.027	1.296	1.323
	1.119	1.538	1.127	2.372	2.181
	1.455	1.757	1.050	1.979	2.131
	.911	1.230	2.103	1.282	1.487
	.826	1.063	2.152	2.122	2.212
	1.301	1.624	1.626	1.946	2.118
	1.426	1.996	1.781	1.839	1.693
$\bar{\delta}_a$	1.219	1.411	1.558	1.733	1.800
σ	.209	.316	.439	.399	.327
t(time delay)	Control	1.23	[b]2.18	[b]3.31	[b]3.74

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(e) Elevator deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.375	0.420	0.441	0.432	0.579
	.387	.335	.381	.454	.655
	.351	.282	.365	.451	.499
	.365	.357	.498	.466	.494
	.476	.515	.477	.715	.946
	.396	.583	.389	.752	.719
	.364	.401	.678	.503	.494
	.308	.351	.579	.719	.543
	.469	.625	.597	.690	.960
	.477	.659	.549	.584	.622
$\bar{\delta}_e$	0.397	0.453	0.495	0.577	0.651
σ	.058	.133	.104	.130	.176
t (time delay)	Control	.99	1.74	[b]3.18	[b]4.50

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(f) Audio task tracking error, volts (460 Hz/volt)

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.454	0.625	0.277	0.374	0.469
	.387	.480	.394	.516	.745
	.368	.260	.328	.490	.535
	.446	.334	.661	.680	.409
	.519	.689	.307	.612	.582
	.516	.814	.260	.543	.464
	.214	.208	.387	.362	.452
	.283	.221	.289	.496	.455
	.292	.376	.497	.658	.684
	.665	.422	.461	.629	.743
$\bar{\varepsilon}_s$	0.414	0.442	0.385	0.535	0.554
σ	.134	.208	.124	.113	.128
t(time delay)	Control	.42	.45	1.85	[b]2.14

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Continued

(g) Audio task thumb-wheel deflection, volts (22.9 deg/volt)

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	1.102	1.342	0.763	1.017	1.212
	1.032	1.171	1.057	1.319	1.576
	1.016	.772	.979	1.195	1.426
	1.161	.896	1.523	1.538	1.164
	1.262	1.586	.823	1.685	1.648
	1.134	1.884	.644	1.360	1.142
	.673	.633	1.127	.886	1.220
	.693	.598	.825	1.158	1.097
	.904	.891	1.208	1.575	1.525
	1.540	1.009	1.064	1.452	1.682
$\bar{\delta}_s$	1.052	1.078	1.001	1.319	1.369
σ	.258	.419	.255	.255	.226
t(time delay)	Control	.20	.39	2.05	[b]2.44

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE IV.- Concluded

(h) Audio task thumb-wheel input frequency, Hz

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.81	0.73	0.93	1.17	0.86
	.96	.69	.99	1.01	1.14
	.81	.67	.96	1.26	1.02
	1.17	.87	1.07	.88	1.36
	.78	.68	.67	1.13	1.24
	.53	.71	1.08	.64	1.33
	.85	.86	.64	1.18	.74
	.78	.73	1.07	.91	1.08
	1.02	.65	.66	.83	1.06
	.67	.73	.71	.83	.74
$\bar{\omega}_{\delta_s}$	0.84	0.75	0.88	.98	1.06
$\bar{\sigma}$	.18	.09	.19	.20	.22
t(time delay)	Control	1.11	.50	1.75	[b]2.75

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE V.- SUMMARY OF DATA FOR ADDING TASK

(a) Total error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	3.545	3.805	3.962	4.385	4.309
	3.770	3.560	3.779	3.979	4.029
	3.220	3.219	3.582	3.660	4.045
	3.247	3.233	3.689	3.542	3.717
	3.482	3.424	3.454	3.443	4.135
	3.446	3.684	3.445	3.693	3.677
	3.407	3.415	3.585	3.802	4.764
	3.577	3.540	3.673	3.604	4.634
	3.343	3.235	3.395	3.393	4.287
	3.458	3.428	3.471	3.616	3.801
$\bar{\epsilon}_v + \bar{\epsilon}_h$	3.450	3.454	3.604	3.712	4.140
$\bar{\sigma}$	.162	.197	.176	.290	.367
t(time delay)	Control	.04	1.37	[b]2.33	[b]6.16

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE V.- Continued

(b) Vertical error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	2.807	2.898	3.031	3.308	3.147
	2.825	2.835	2.831	3.078	2.947
	2.764	2.787	2.937	2.925	2.926
	2.739	2.763	2.912	2.849	2.845
	2.879	2.804	2.948	2.908	3.038
	2.831	2.987	2.751	2.961	2.978
	2.858	2.886	2.939	3.070	3.573
	2.924	2.928	3.029	2.945	3.428
	2.759	2.725	2.813	2.749	3.238
	2.803	2.722	2.868	2.797	3.036
$\bar{\varepsilon}_v$	2.819	2.834	2.906	2.959	3.116
$\bar{\sigma}$	.058	.089	.091	.161	.234
t(time delay)	Control	.24	1.37	[b]2.21	[b]4.68

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE V.- Continued

(c) Horizontal error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.739	0.907	0.931	1.077	1.162
	.945	.725	.947	.902	1.082
	.456	.431	.645	.735	1.119
	.509	.470	.777	.693	.871
	.603	.620	.506	.732	1.097
	.615	.697	.694	.534	.699
	.549	.529	.646	.731	1.191
	.653	.612	.644	.659	1.206
	.584	.509	.583	.644	1.048
	.655	.706	.603	.819	.765
$\bar{\varepsilon}_h$	0.631	0.621	0.698	0.753	1.024
σ	.136	.144	.145	.151	.181
t(time delay)	Control	.15	.98	1.79	[b]5.79

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE V.- Continued

(d) Aileron deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	2.209	2.201	2.010	3.519	2.257
	1.838	2.053	1.936	2.049	2.147
	1.455	1.540	2.000	1.565	2.267
	1.483	1.521	1.864	1.952	2.507
	1.486	1.474	1.472	1.906	2.041
	1.234	1.431	1.963	2.243	2.188
	1.888	1.568	1.879	1.706	2.712
	1.795	1.826	2.186	1.810	2.402
	1.173	1.587	1.672	1.842	2.406
	1.181	1.507	1.355	1.696	1.724
$\bar{\delta}_a$	1.574	1.671	1.834	2.029	2.265
$\bar{\sigma}$	.347	.265	.258	.558	.271
t(time delay)	Control	.60	1.62	[b]2.84	[b]4.32

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE V.- Concluded

(e) Elevator deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.738	0.861	0.696	1.214	0.962
	.584	.803	.807	.887	.832
	.517	.510	.641	.573	.675
	.442	.497	.522	.562	.623
	.447	.476	.512	.553	.669
	.409	.536	.485	.524	.555
	.532	.605	.542	.620	.887
	.406	.430	.564	.584	.705
	.498	.470	.468	.613	.795
	.412	.521	.485	.445	.639
$\bar{\delta}_e$	0.498	0.571	0.572	0.658	0.734
$\bar{\sigma}$	.103	.146	.110	.226	.129
t(time delay)	Control	1.09	1.10	[b]2.38	[b]3.53

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VI.- SUMMARY OF DATA WITH NO SECONDARY TASK

(a) Total error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	3.499	3.463	3.233	3.669	4.120
	3.583	3.790	3.881	3.909	4.198
	3.793	3.155	3.491	3.699	3.848
	3.549	3.511	3.670	4.096	4.667
	3.268	3.805	4.026	4.896	5.528
	4.353	3.716	3.687	3.507	4.477
	3.584	3.458	3.287	3.559	4.036
	3.131	3.232	3.381	3.529	3.753
	3.344	3.484	3.468	3.382	3.582
	3.491	3.452	3.570	3.751	3.838
$\bar{\epsilon}_v + \bar{\epsilon}_h$	3.541	3.507	3.569	3.800	4.205
$\bar{\sigma}$	.344	.216	.253	.437	.570
t(time delay)	Control	.20	.17	1.50	[b]3.84

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VI.- Continued

(b) Vertical error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	2.695	2.882	2.694	3.005	3.206
	2.895	3.057	2.977	3.079	3.192
	2.899	2.746	2.800	2.868	3.050
	2.854	2.764	2.948	3.022	3.055
	2.725	3.016	3.062	3.420	3.547
	3.014	2.880	2.919	2.791	3.477
	2.928	2.775	2.769	2.875	2.854
	2.717	2.757	2.812	2.994	2.911
	2.707	2.760	2.827	2.634	3.037
	2.775	2.761	2.868	3.009	3.038
$\bar{\bar{\varepsilon}}_v$	2.821	2.840	2.868	2.970	3.137
$\bar{\sigma}$	.112	.115	.109	.207	.225
t(time delay)	Control	.26	.64	2.05	[b]4.35

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VI.- Continued

(c) Horizontal error, m

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.804	0.581	0.538	0.664	0.914
	.688	.734	.904	.830	1.006
	.894	.408	.691	.831	.798
	.695	.747	.722	1.074	1.612
	.543	.789	.964	1.475	1.980
	1.340	.835	.767	.716	1.001
	.655	.683	.517	.684	1.182
	.413	.475	.568	.535	.843
	.594	.724	.640	.748	.545
	.569	.691	.702	.742	.799
$\bar{\sigma}_h$	0.720	0.667	0.702	0.830	1.068
σ	.256	.137	.148	.266	.427
t(time delay)	Control	.44	.15	.92	[b]2.90

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VI.- Continued

(d) Aileron deflection ($\times 10^2$), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	1.415	1.448	2.213	0.970	1.637
	1.449	1.288	1.469	1.574	1.908
	1.220	1.137	1.625	1.950	1.929
	1.242	1.182	1.334	1.961	2.184
	1.271	1.594	1.310	1.575	1.587
	1.239	1.460	1.717	1.857	1.630
	1.515	1.639	1.651	2.480	2.161
	1.120	1.430	1.512	1.742	2.371
	1.495	1.496	1.557	1.468	2.137
	1.046	1.573	1.600	2.323	2.564
$\bar{\delta}_a$	1.301	1.425	1.599	1.790	2.011
σ	.160	.171	.253	.433	.331
t(time delay)	Control	.96	[b]2.31	[b]3.79	[b]5.50

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VI.- Concluded

(e) Elevator deflection (× 10^2), rad

	Units of time delay[a]				
	0	4	8	12	16
	rms data for each run				
	0.437	0.579	0.676	0.710	0.665
	.413	.443	.532	.664	.603
	.426	.373	.560	.562	.800
	.378	.366	.384	.704	.715
	.342	.641	.430	.522	.728
	.413	.441	.626	.653	.684
	.572	.544	.520	.724	.801
	.359	.457	.428	.552	.876
	.400	.451	.411	.580	.767
	.337	.474	.507	.695	.888
$\bar{\delta}_e$	0.408	0.477	0.507	0.637	0.753
$\bar{\sigma}$	.068	.087	.096	.075	.091
t(time delay)	Control	1.84	[b]2.65	[b]6.09	[b]9.18

[a]Each unit of time delay equals 31.25 msec.
[b]Significant difference at 5-percent level.

TABLE VII.- ANALYSIS OF VARIANCE FOR FOUR SECONDARY TASKS

[Critical F values for time delay, task, and delay/task interaction are 2.42, 2.66, and 1.81, respectively]

(a) Total error

Experimental factor	Time delay	Task	Delay/task interaction	Error
Degrees of freedom	4	3	12	180
F	[a]22.50	[a]413.60	[a]4.79	

(b) Vertical error

Experimental factor	Time delay	Task	Delay/task interaction	Error
Degrees of freedom	4	3	12	180
F	[a]22.14	[a]423.13	[a]5.70	

(c) Horizontal error

Experimental factor	Time delay	Task	Delay/task interaction	Error
Degrees of freedom	4	3	12	180
F	[a]10.58	[a]184.59	[a]1.93	

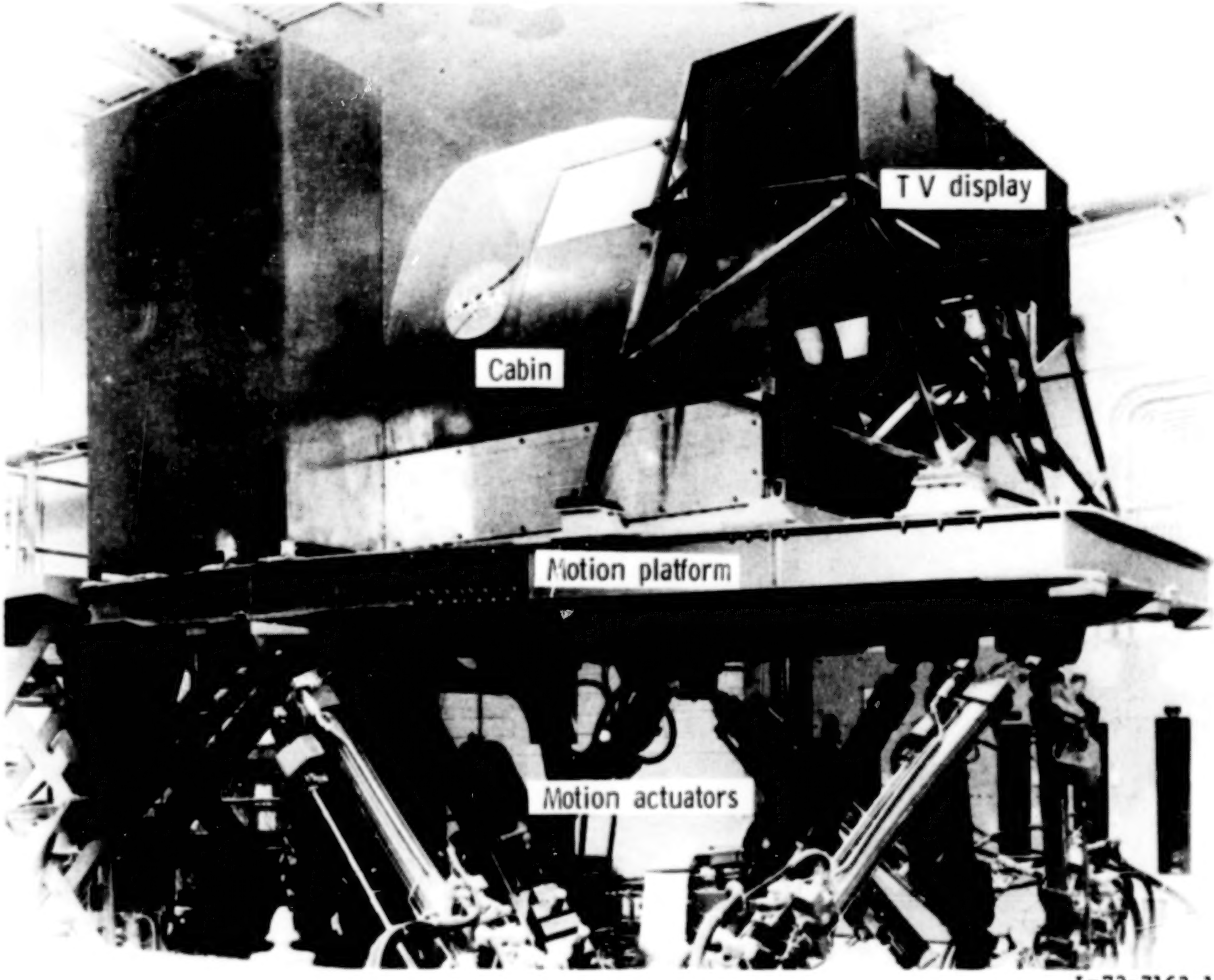
(d) Aileron deflection

Experimental factor	Time delay	Task	Delay/task interaction	Error
Degrees of freedom	4	3	12	180
F	[a]18.21	[a]17.71	0.13	

(e) Elevator deflection

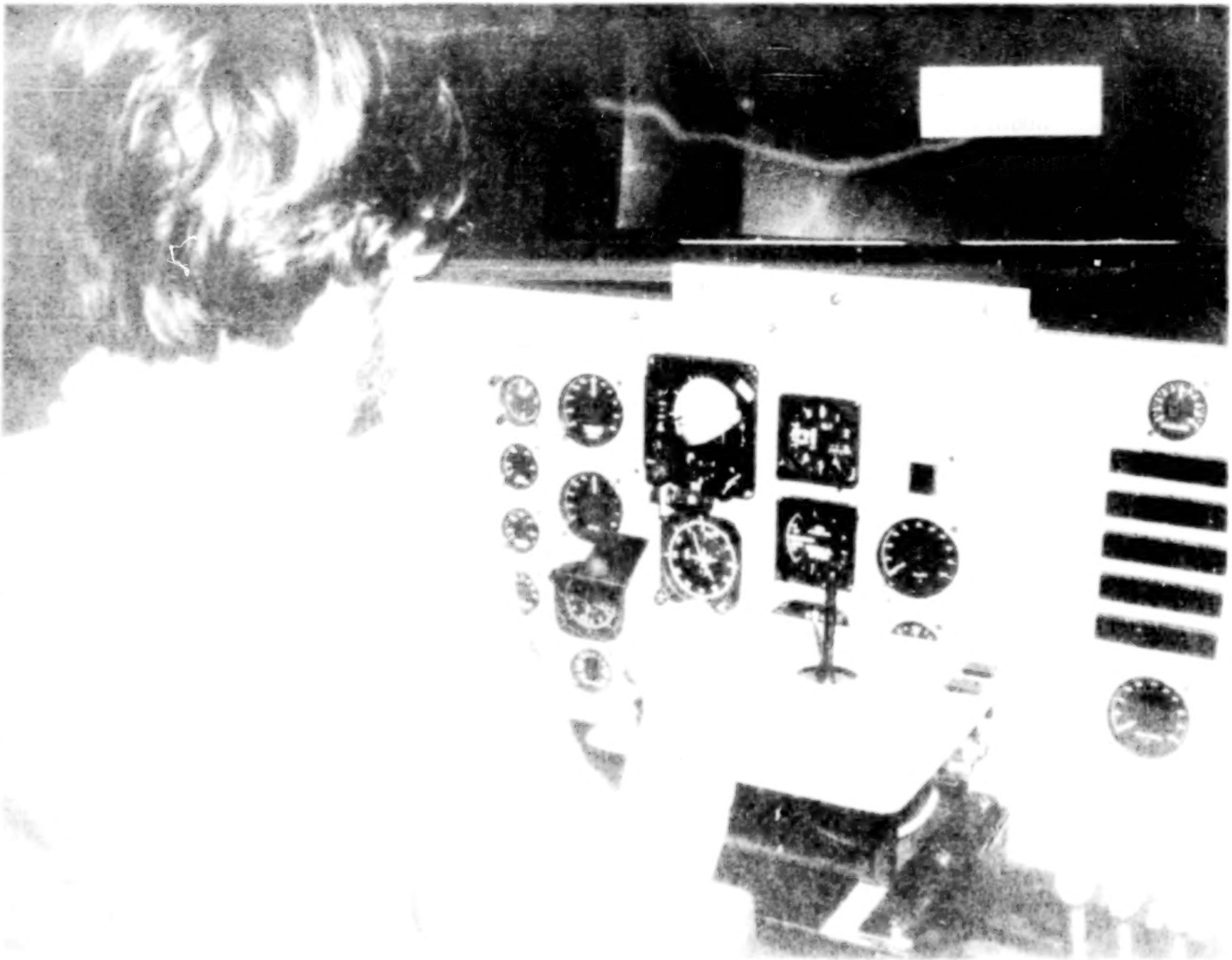
Experimental factor	Time delay	Task	Delay/task interaction	Error
Degrees of freedom	4	3	12	180
F	[a]22.00	[a]10.17	[a]3.33	

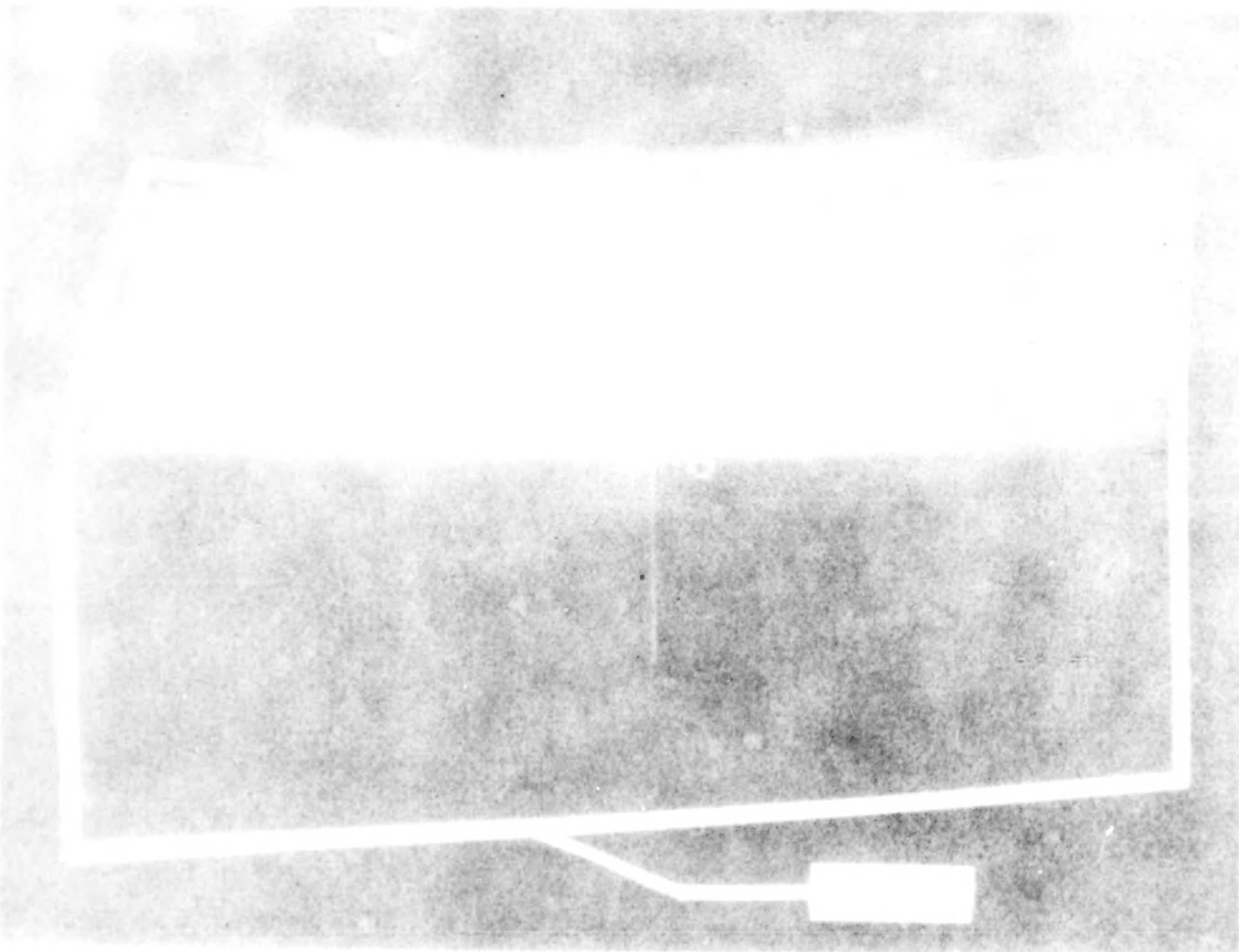
[a]Statistical significance at the 5-percent level.



L-73-7163.1

Figure 1.- Langley six-degree-of-freedom visual-motion simulator.





L-75-3154.1

[illegible] scene on closed-circuit television screen observed by [illegible] aircraft was nearly aligned with target.

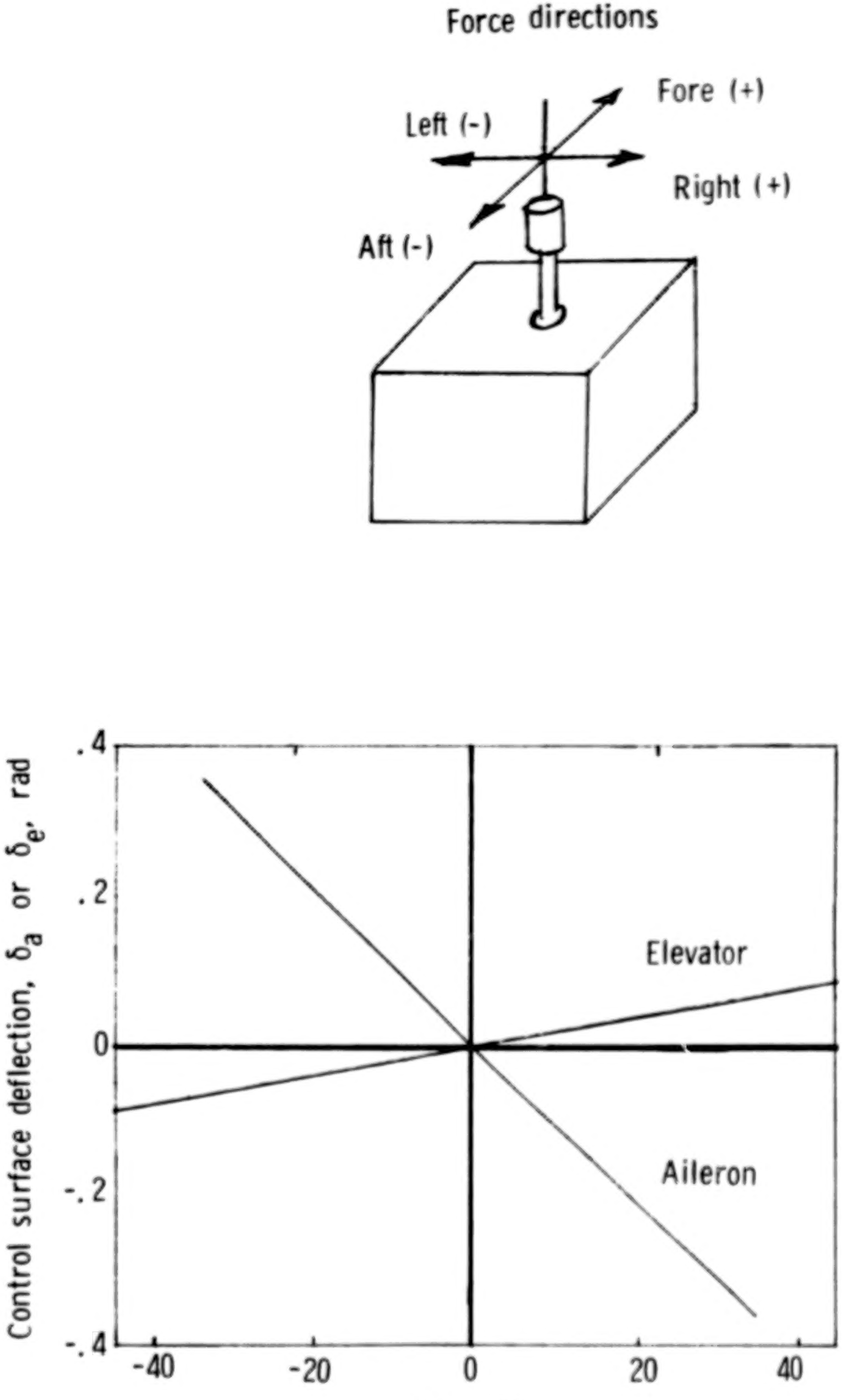


Figure 4.- Two-axis force-stick characteristics.

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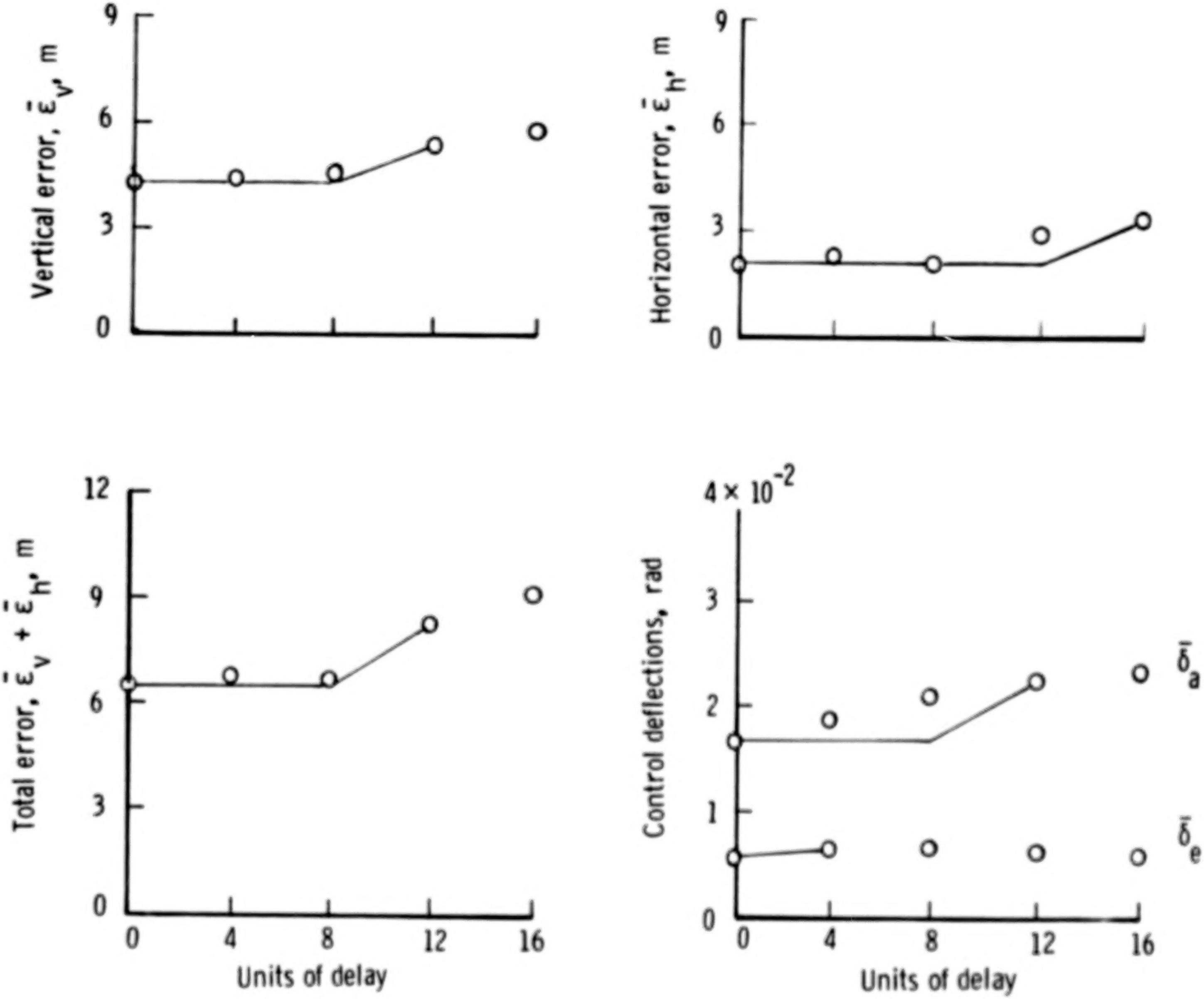


Figure 5.- Performance measures for tapping task. (Lines used to denote statistical significance of time delays.) Data from reference 2.

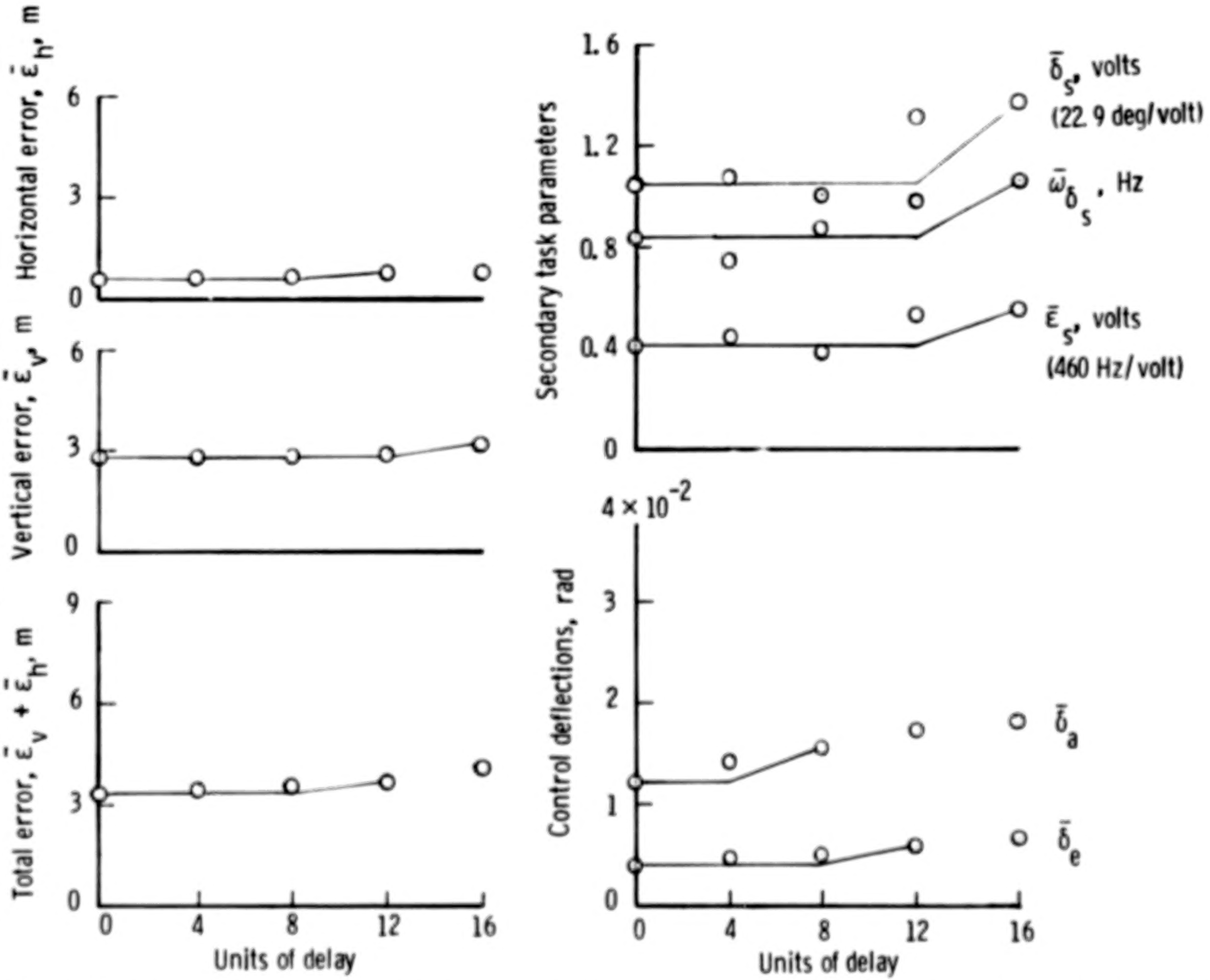


Figure 6.- Performance measures for audio task. (Lines used to denote statistical significance of time delays.) Data from reference 3.

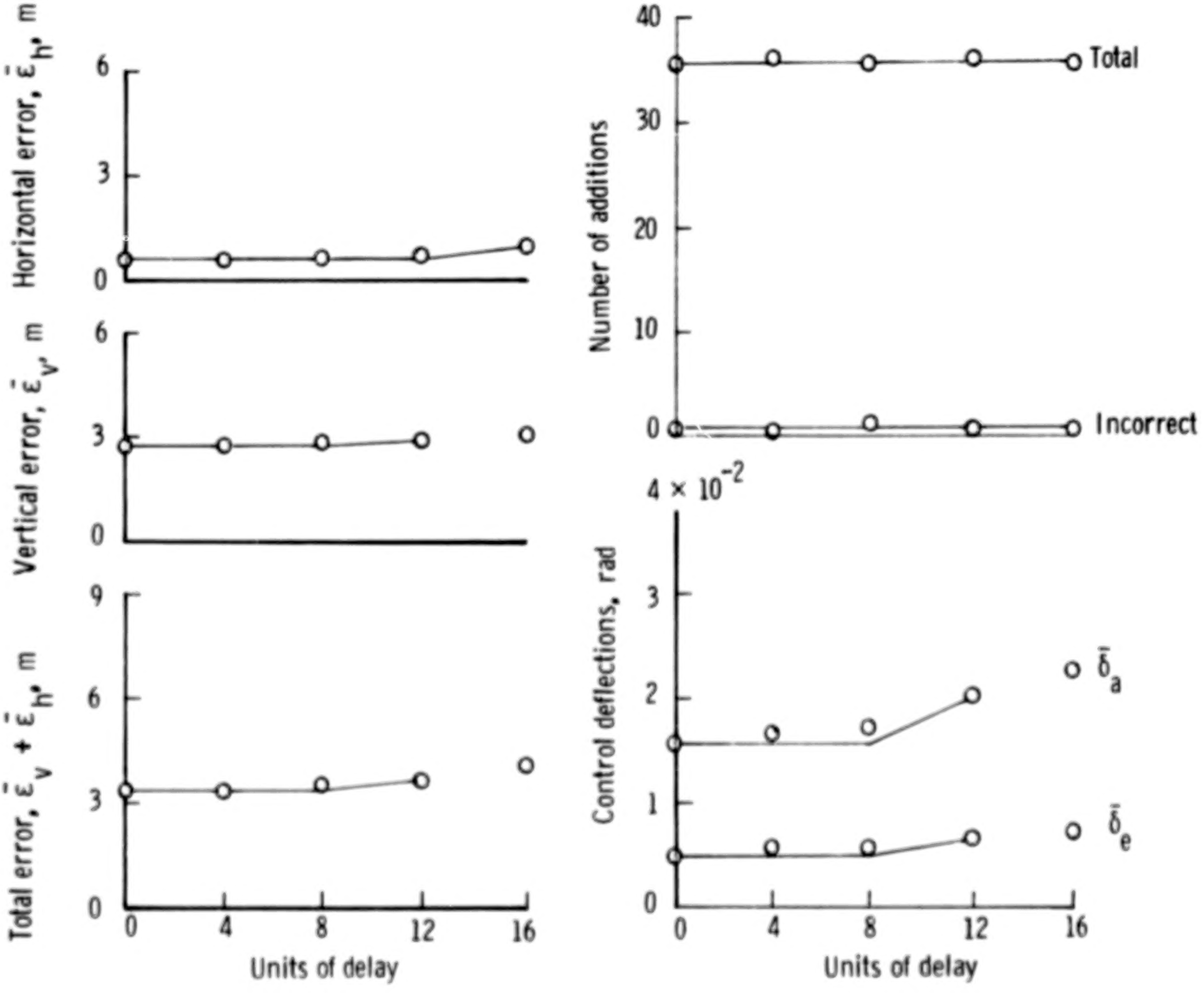


Figure 7.- Performance measures for adding task. (Lines used to denote statistical significance of time delays.)

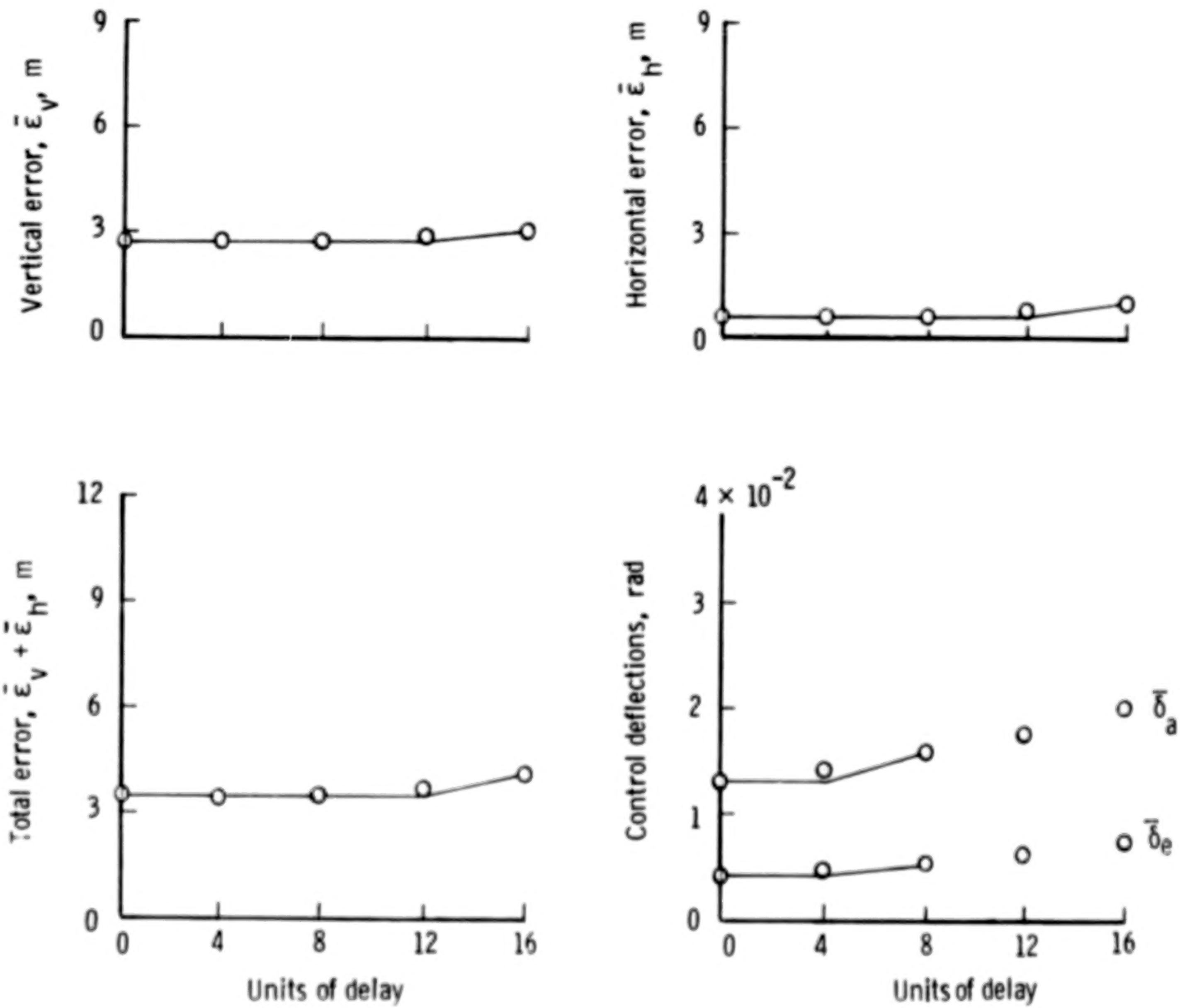
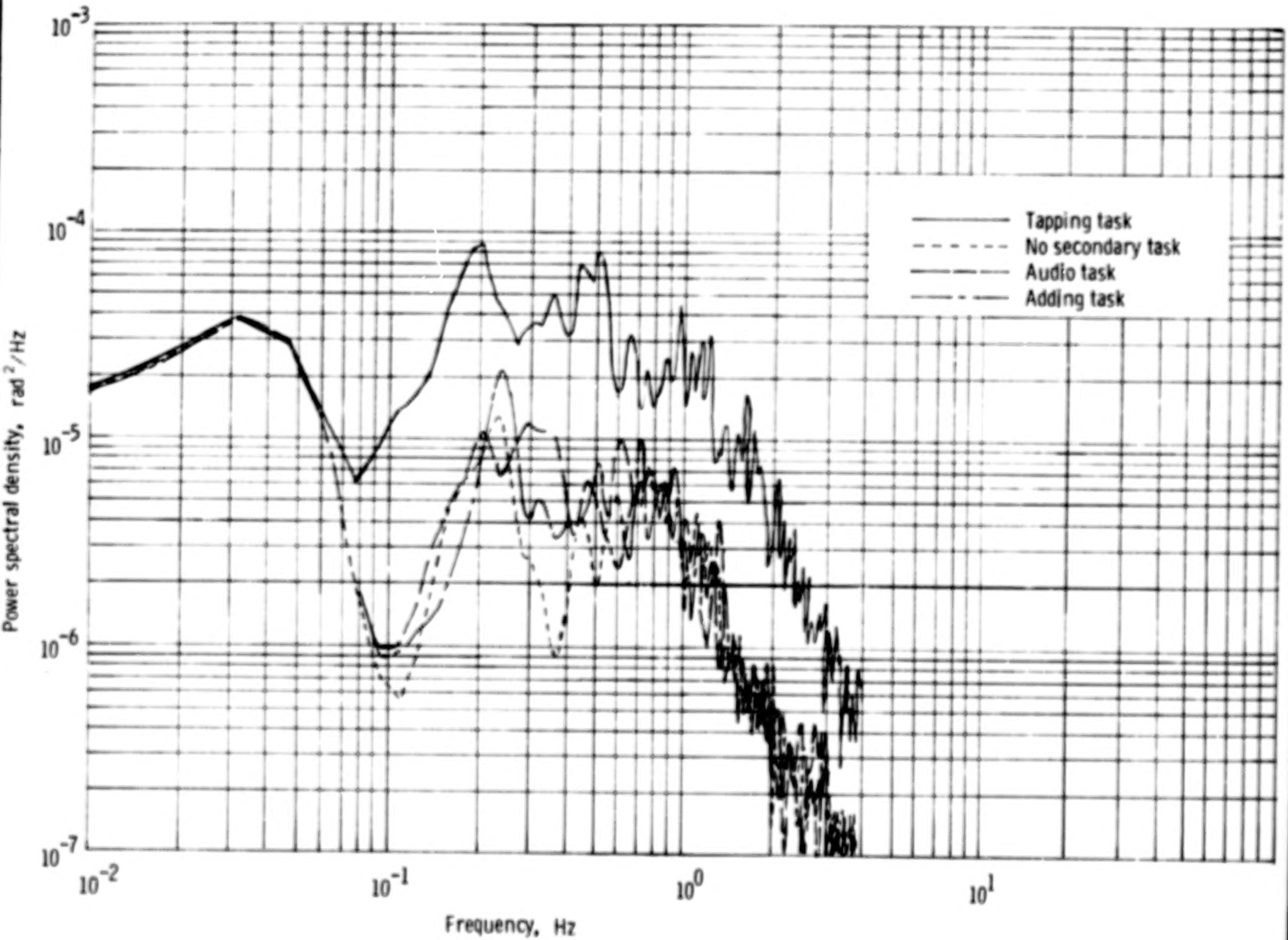
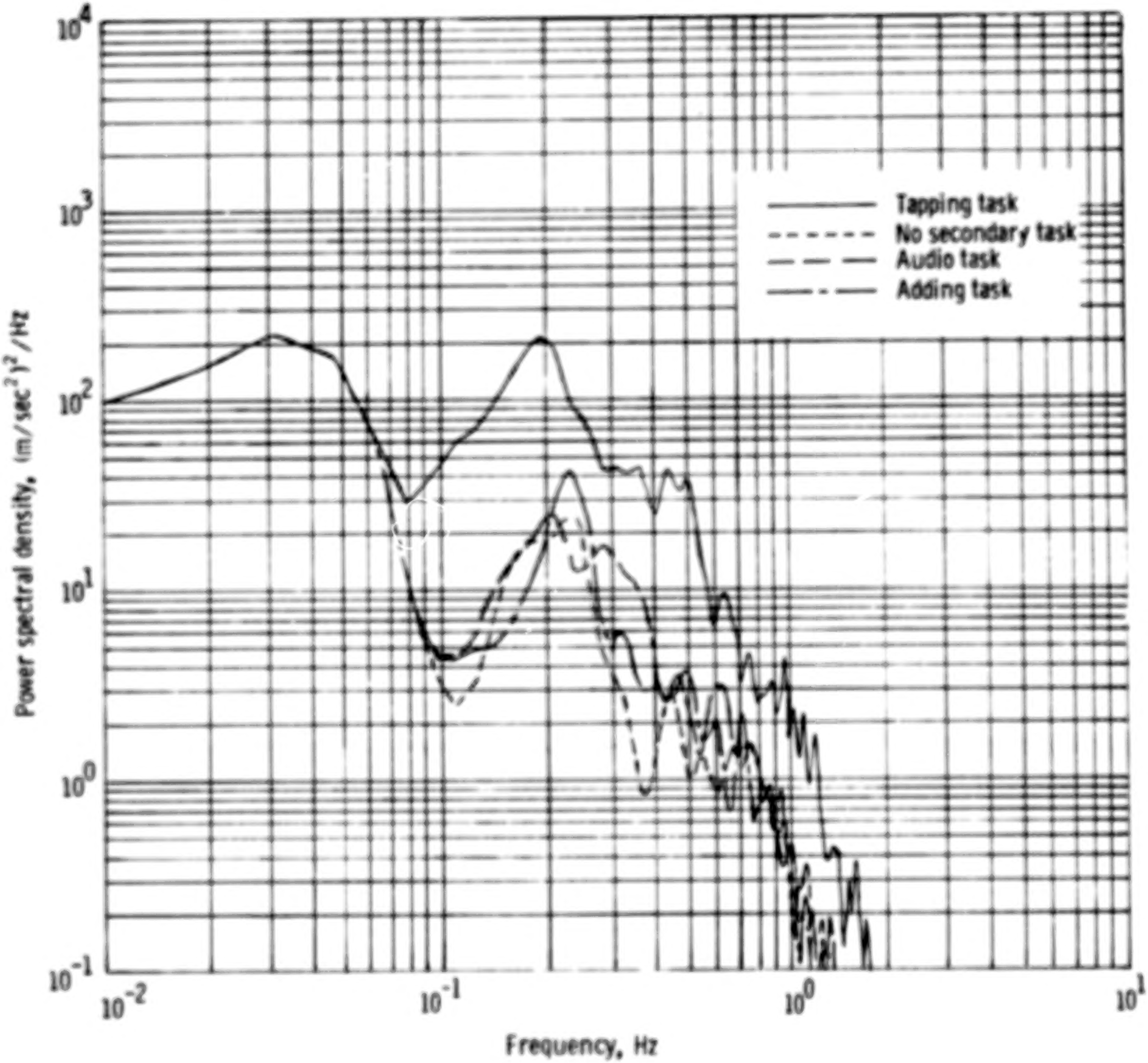


Figure 8.- Performance measures with no secondary tasks. (Lines used to denote statistical significance of time delays.)



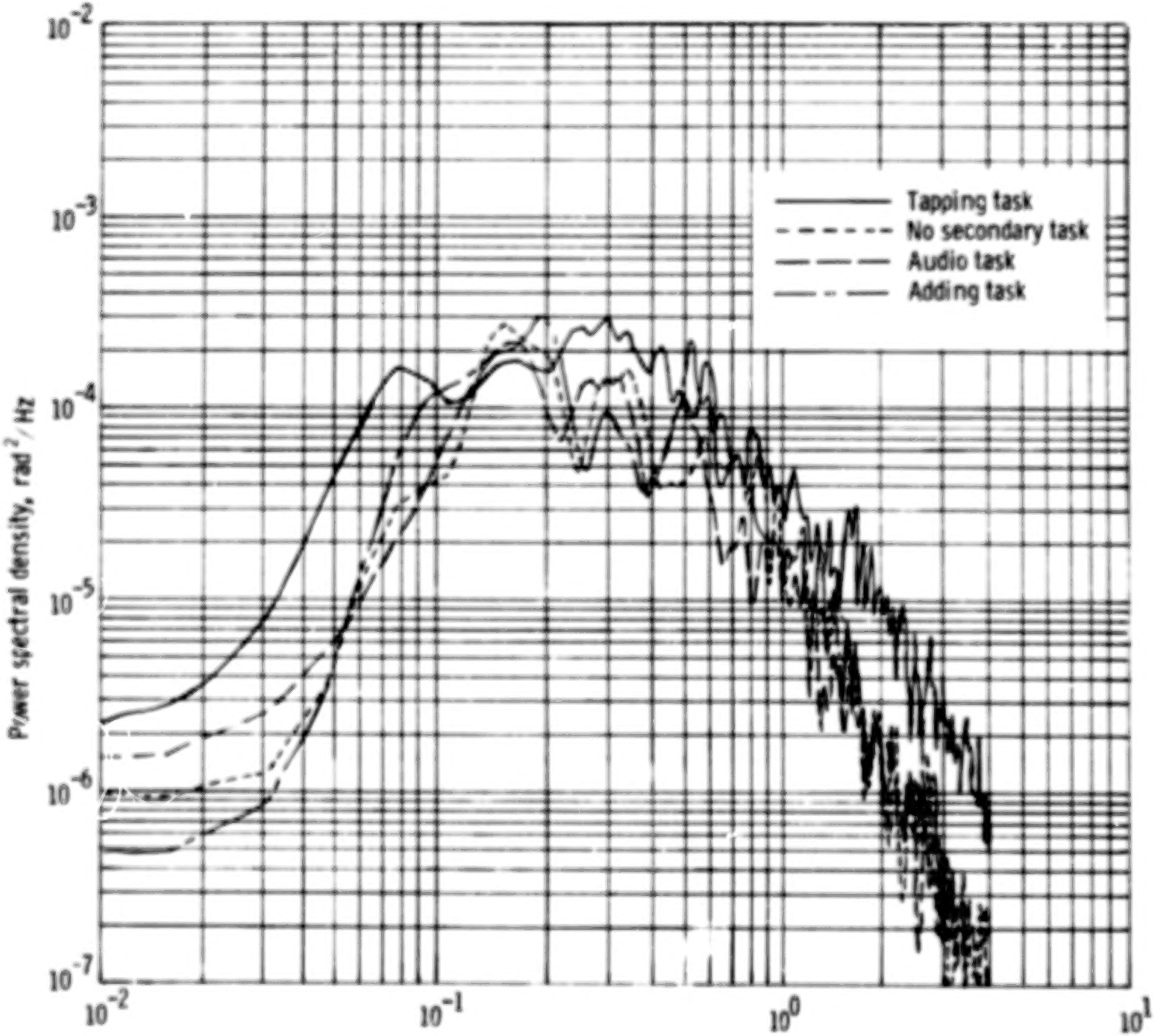
(a) Elevator control inputs δ_e.

Figure 9.- Power spectral densities for typical runs made with zero time delay under motion-base conditions.



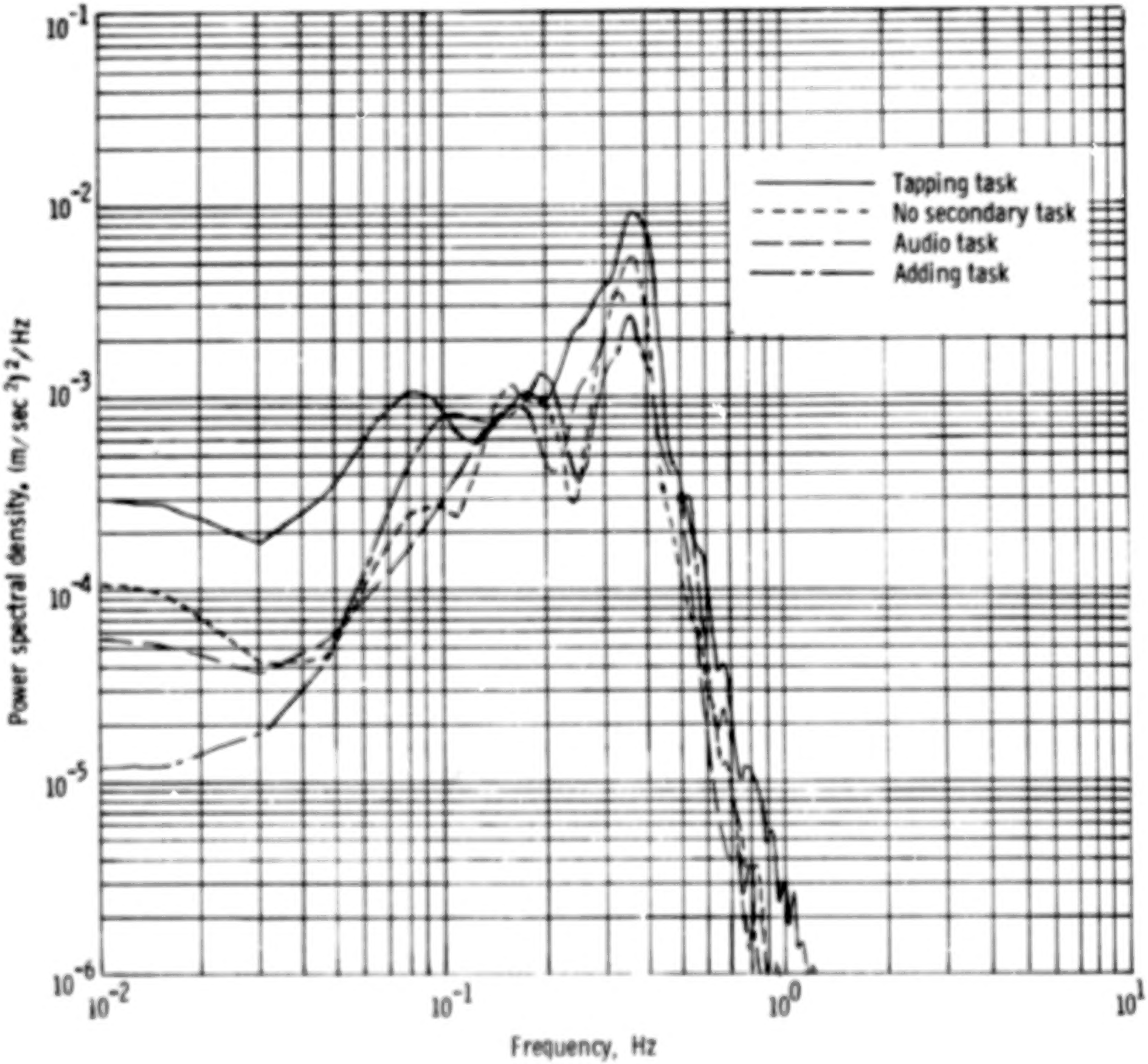
(b) Vertical acceleration a_z.

Figure 9.- Continued.



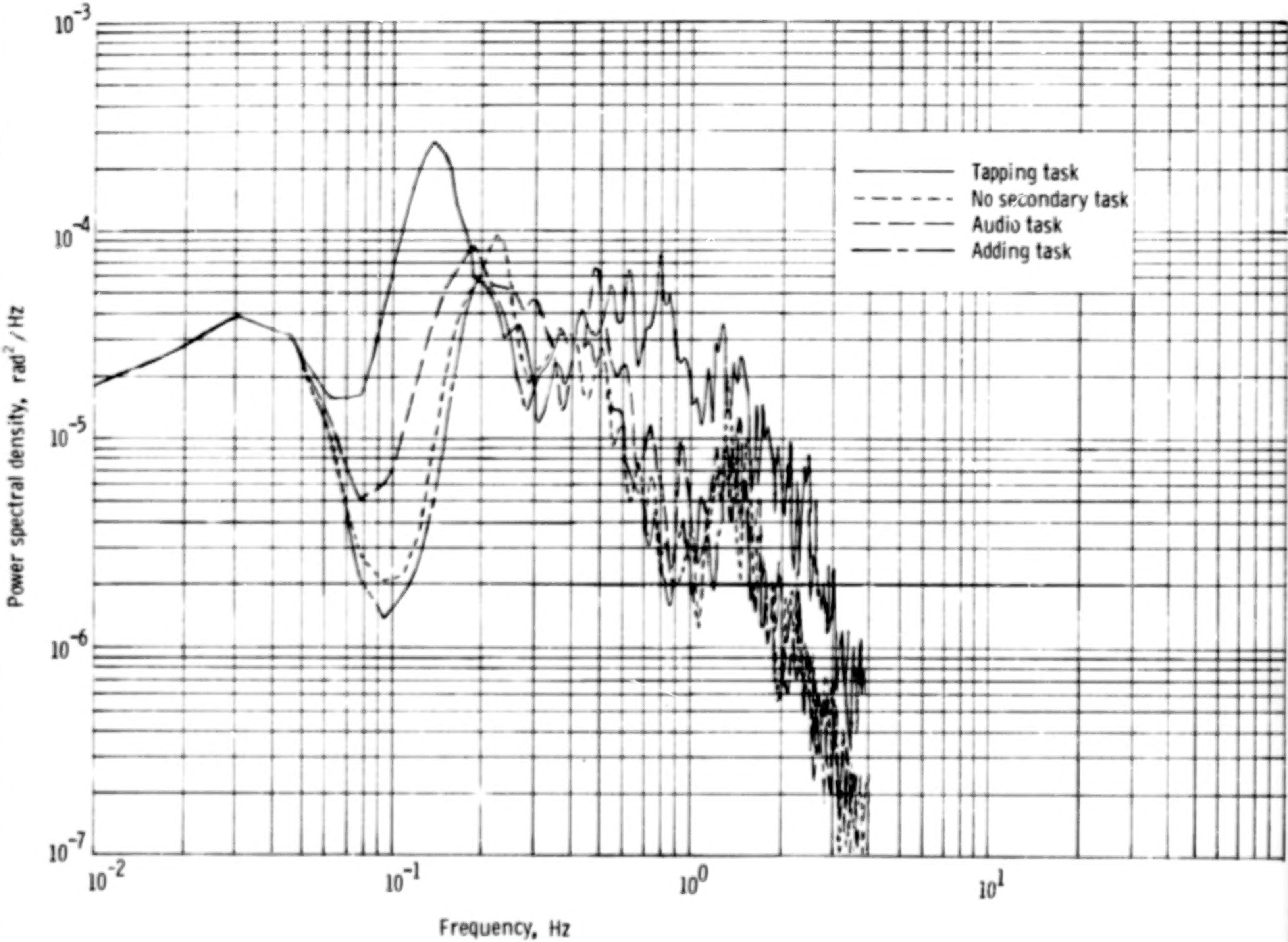
(c) Aileron control inputs δ_a.

Figure 9.- Continued.



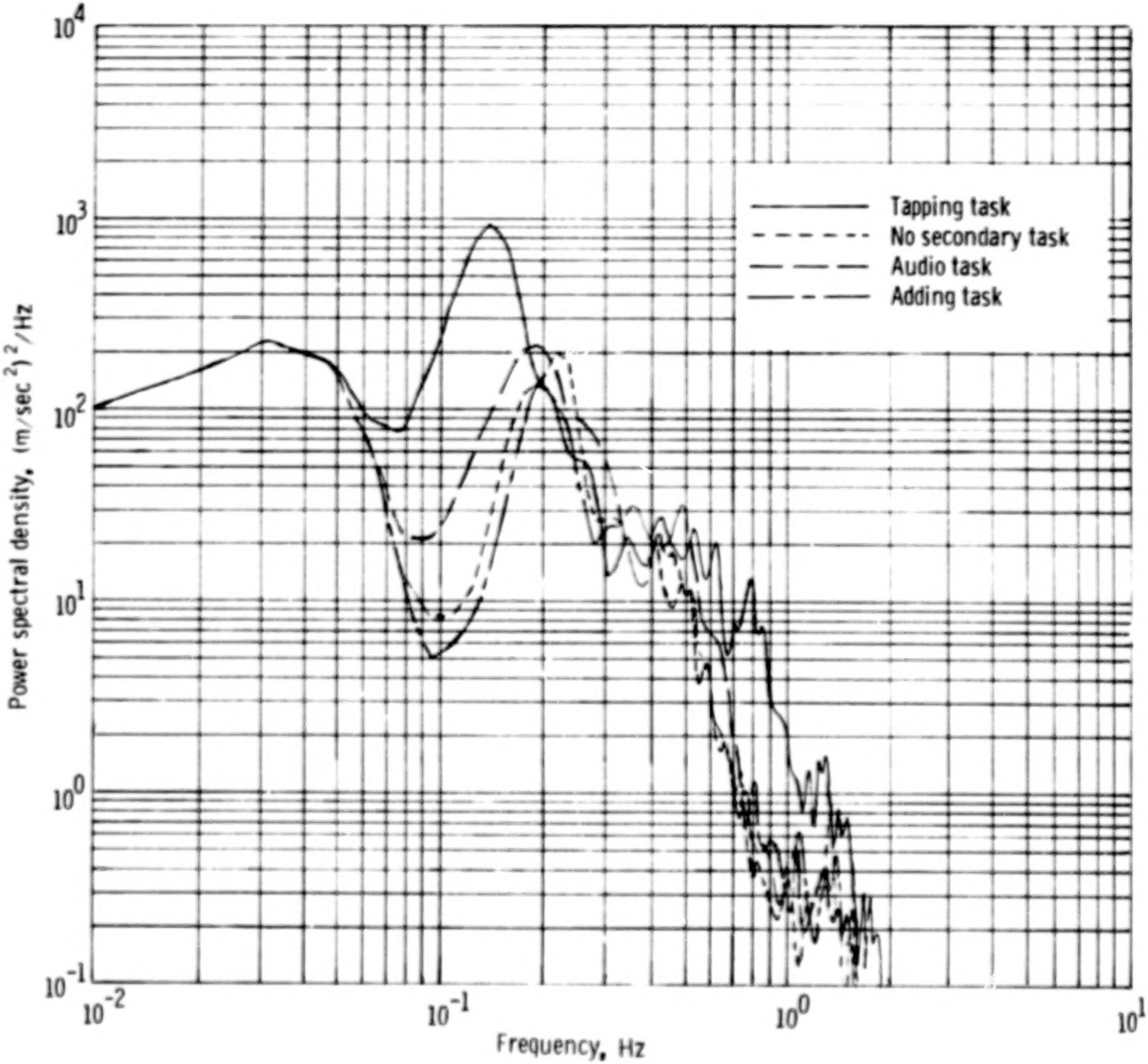
(d) Lateral acceleration a_Y.

Figure 9.- Concluded.



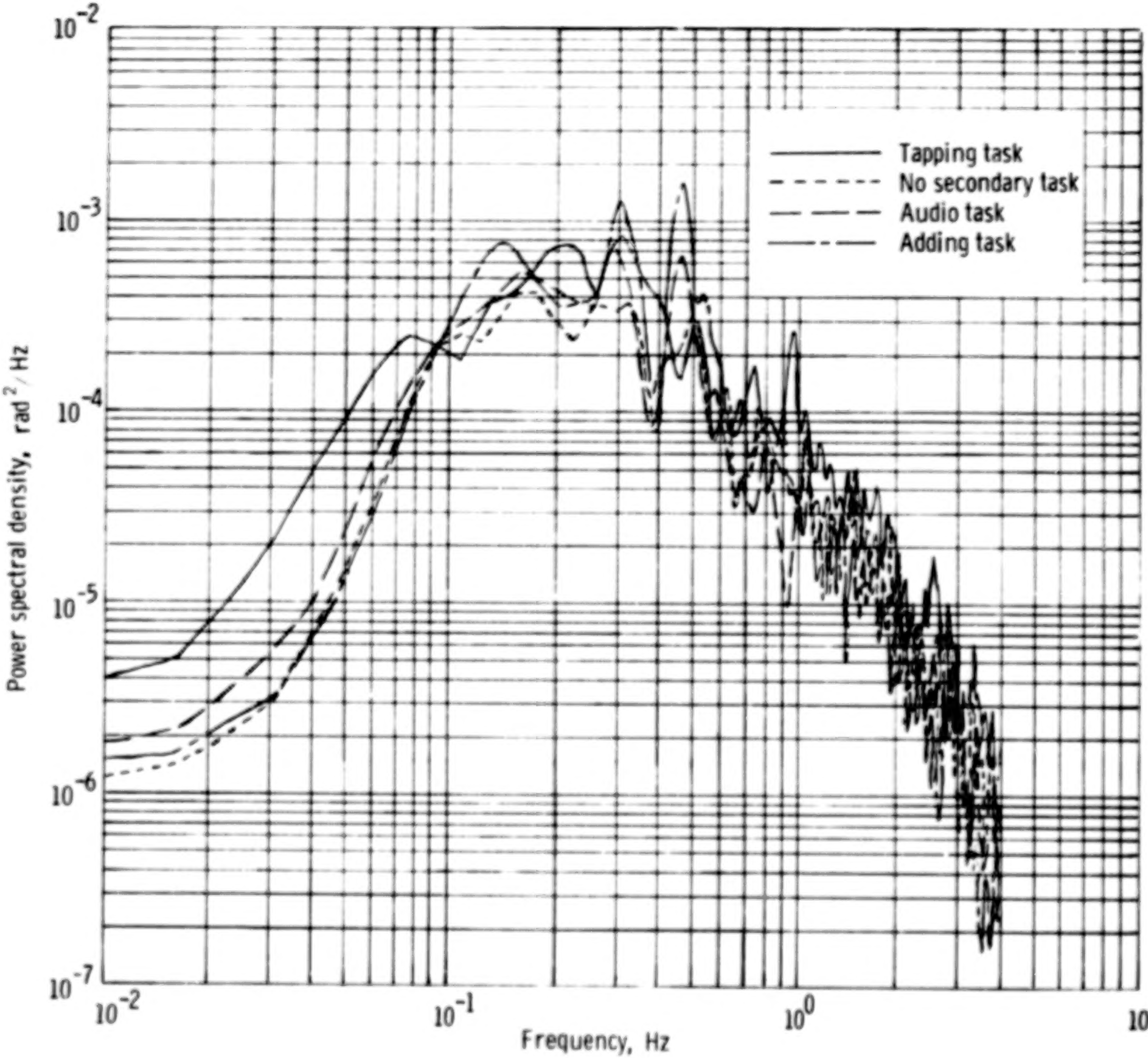
(a) Elevator control inputs δ_e.

Figure 10.- Power spectral densities for typical runs made with 16 units of time delay under motion-base conditions.



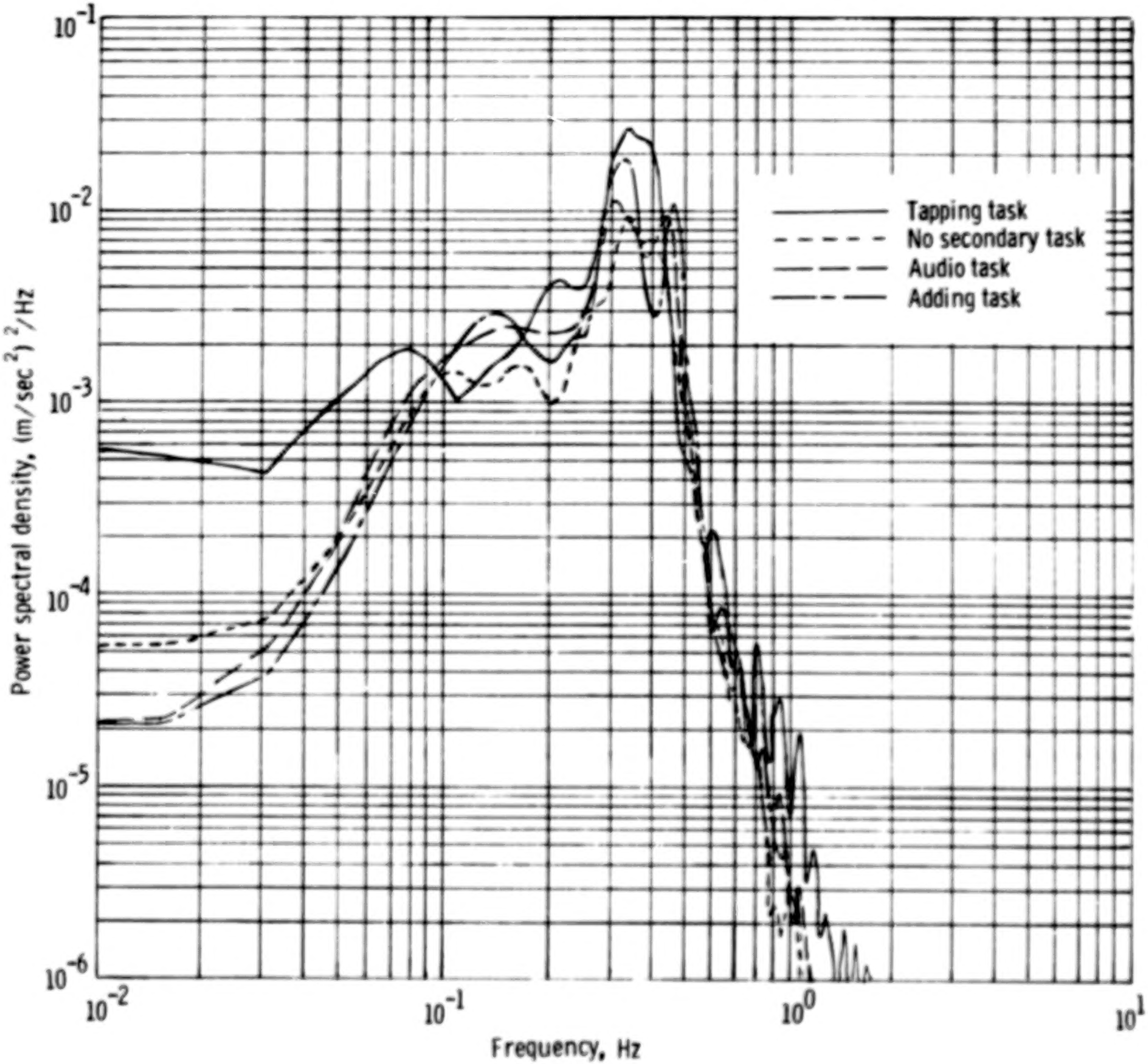
(b) Vertical acceleration a_z.

Figure 10.- Continued.



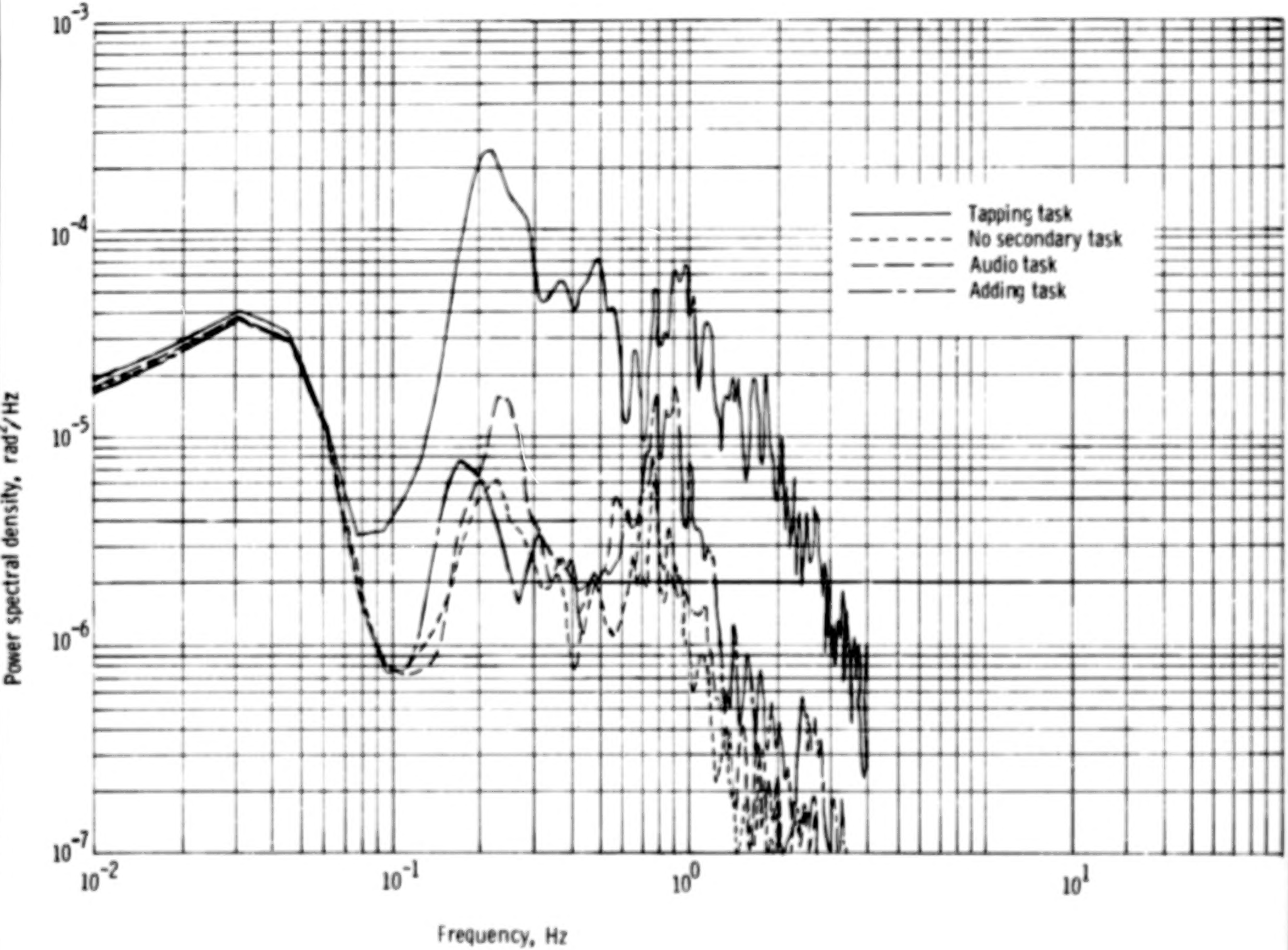
(c) Aileron control inputs δ_a.

Figure 10.- Continued.



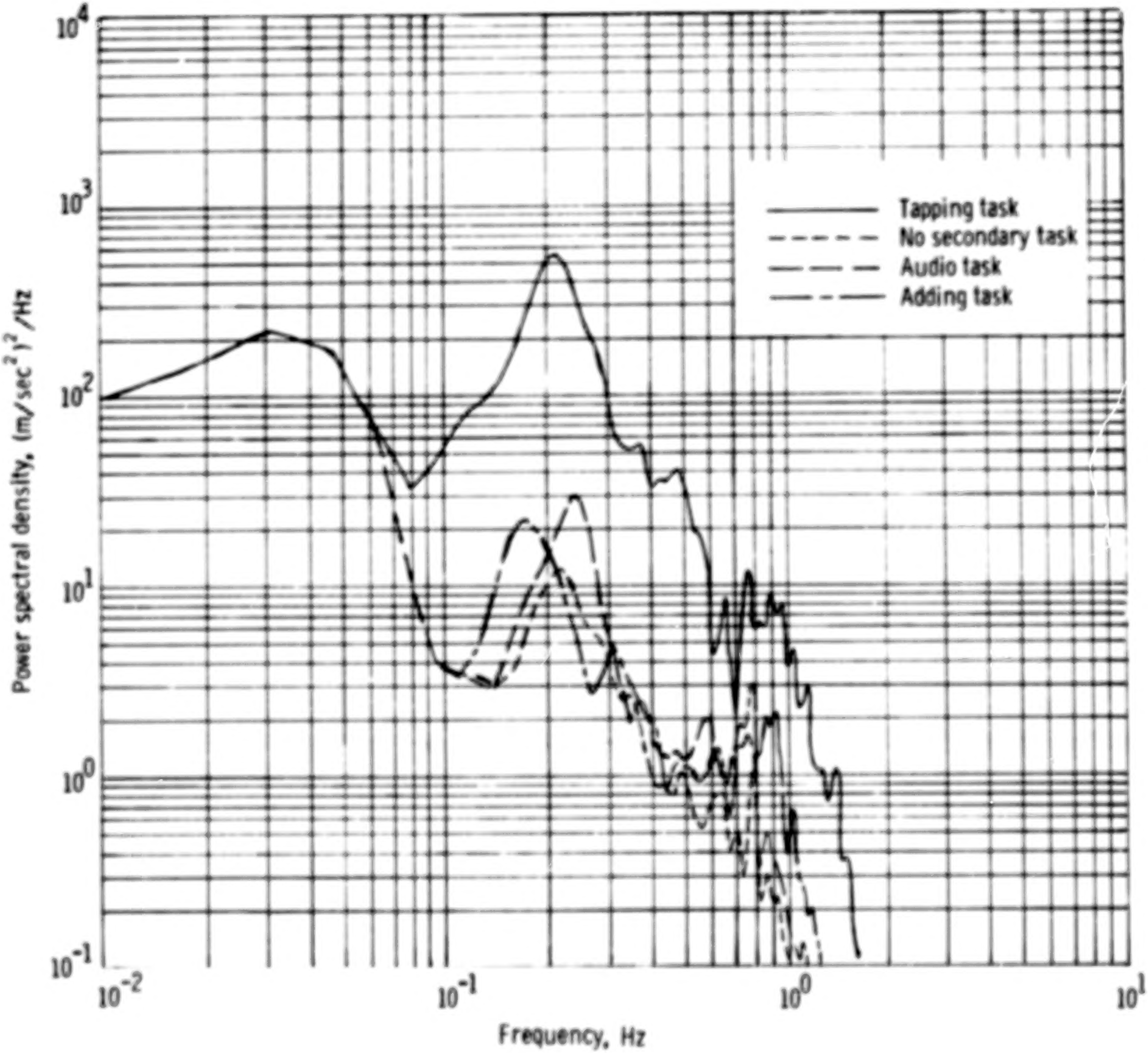
(d) Lateral acceleration a_Y.

Figure 10.- Concluded.



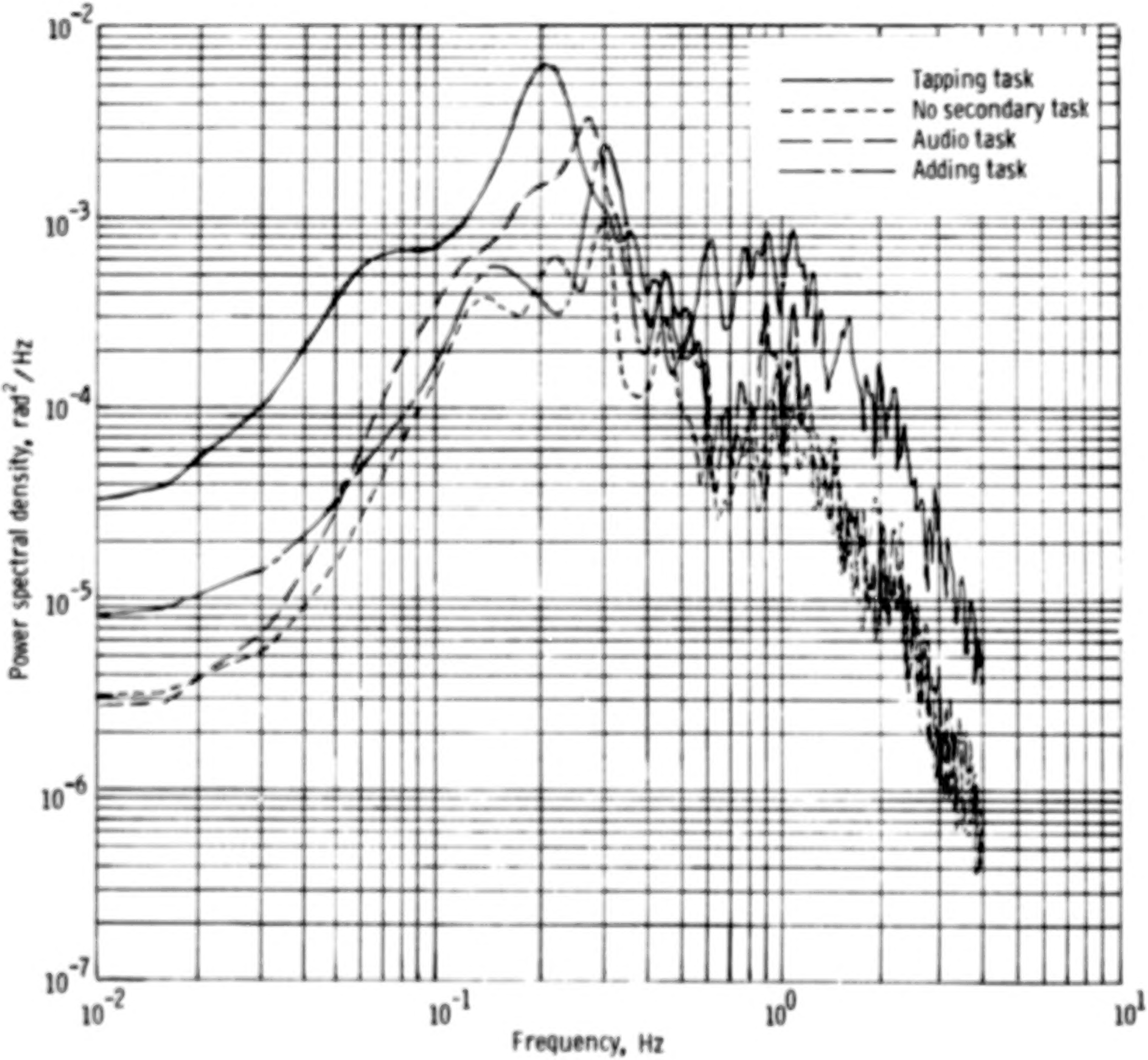
(a) Elevator control inputs δ_e.

Figure 11.- Power spectral densities for typical runs made with zero time delay under fixed-base conditions.



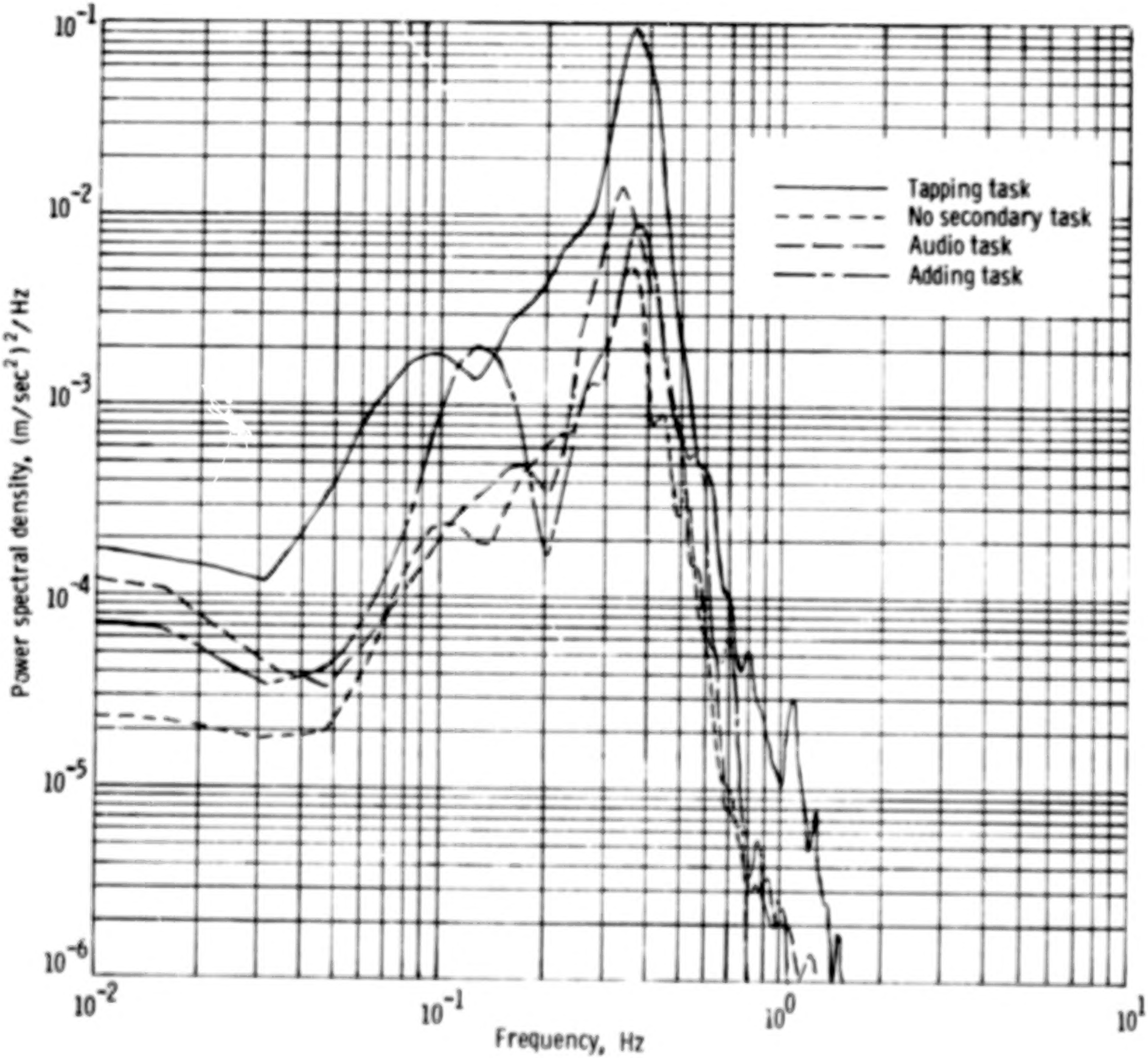
(b) Vertical acceleration a_z.

Figure 11.- Continued.



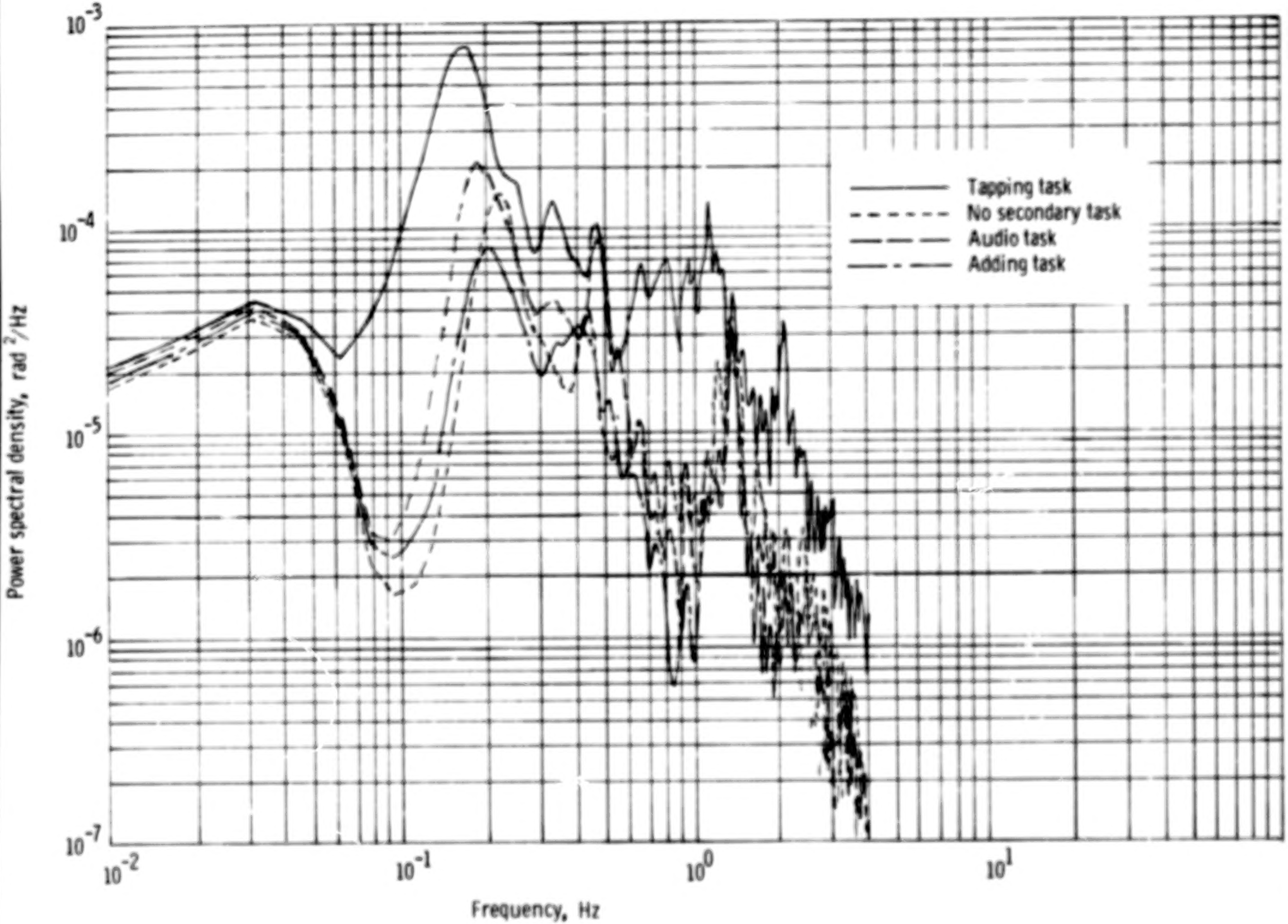
(c) Aileron control inputs δ_a.

Figure 11.- Continued.



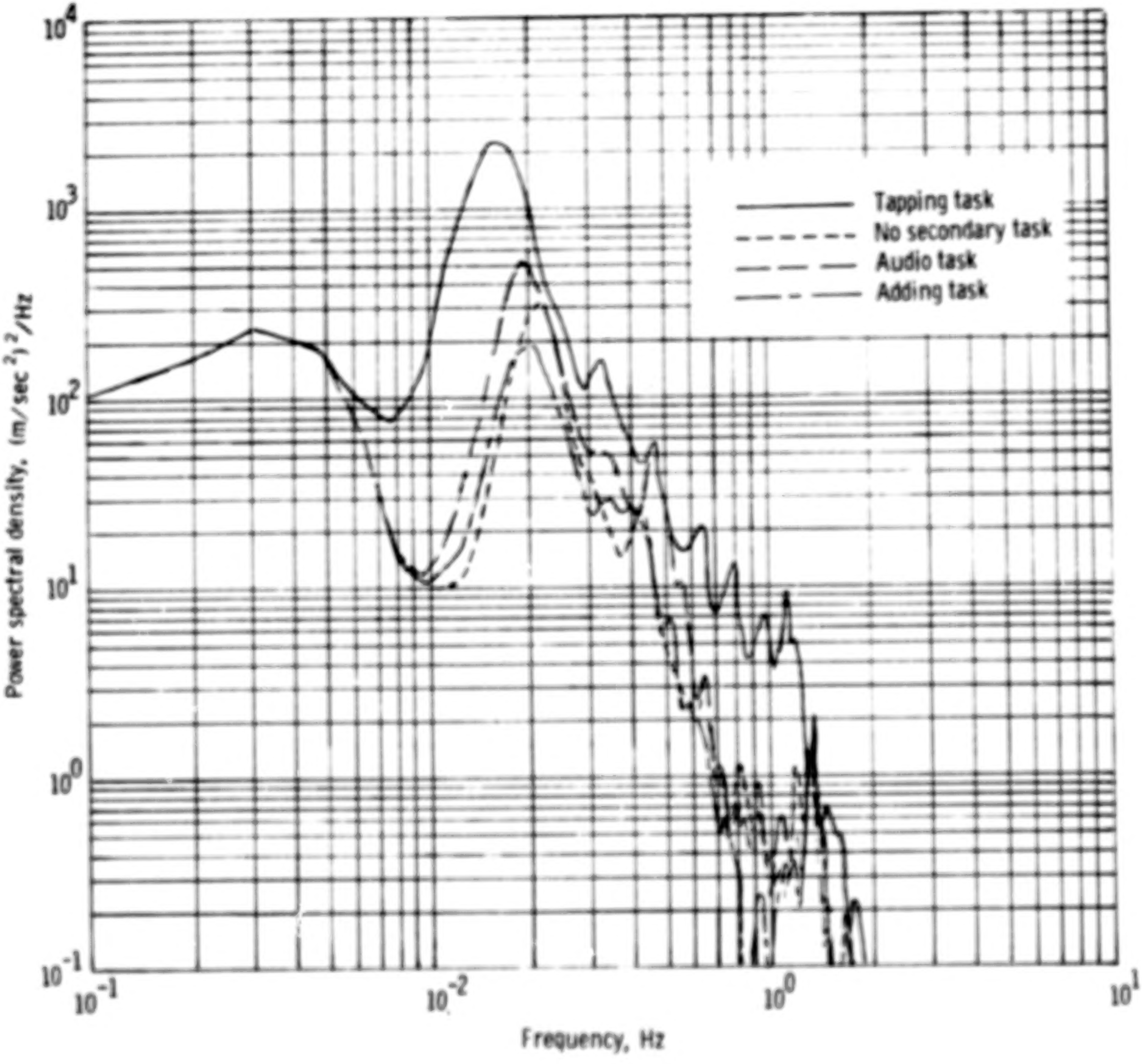
(d) Lateral acceleration a_Y.

Figure 11.- Concluded.



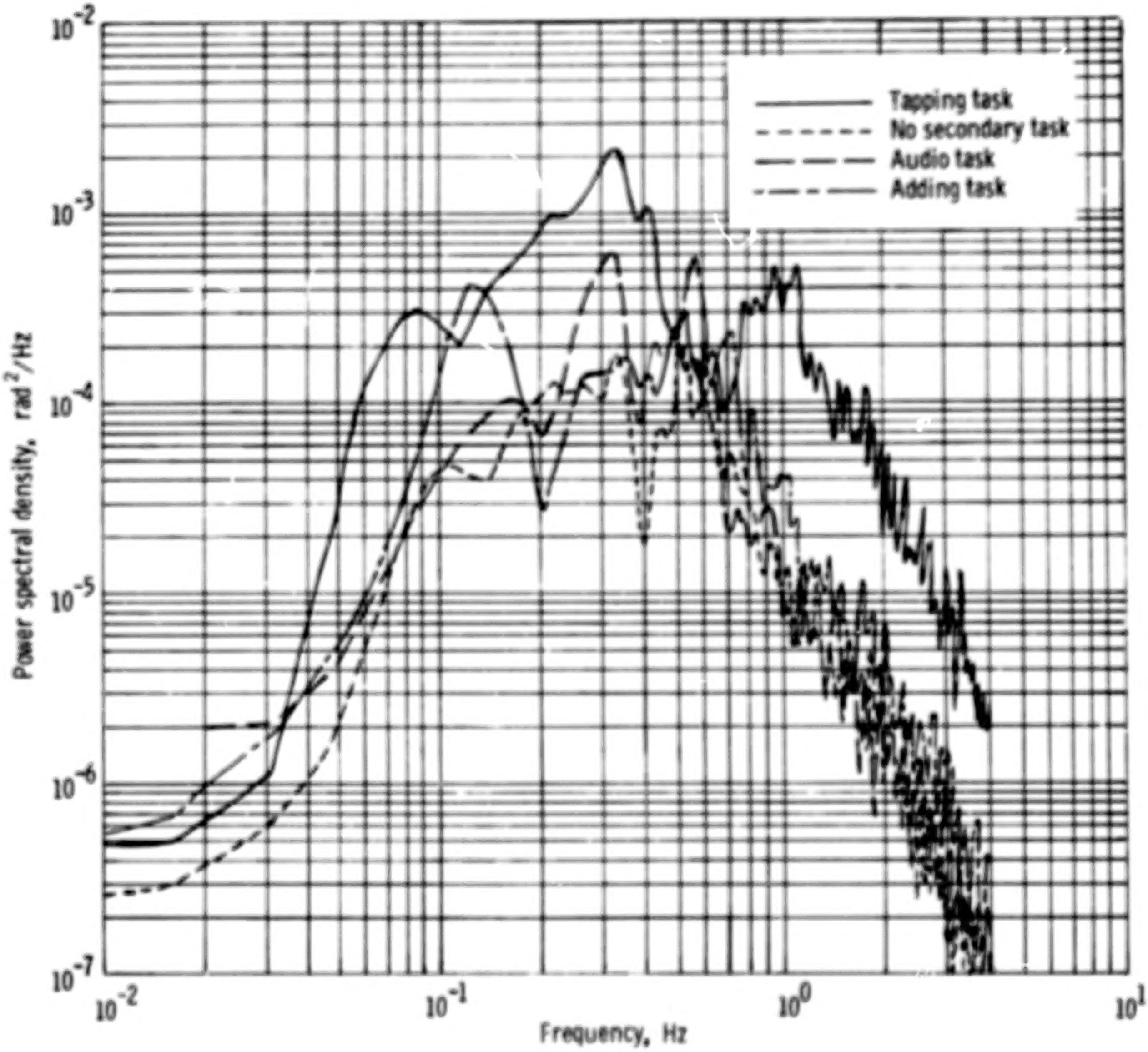
(a) Elevator control inputs δ_e.

Figure 12.- Power spectral densities for typical runs made with 16 units of time delay under fixed-base conditions.



(b) Vertical acceleration a_z.

Figure 12.- Continued.



(c) Aileron control inputs δ_a.

Figure 12.- Continued.

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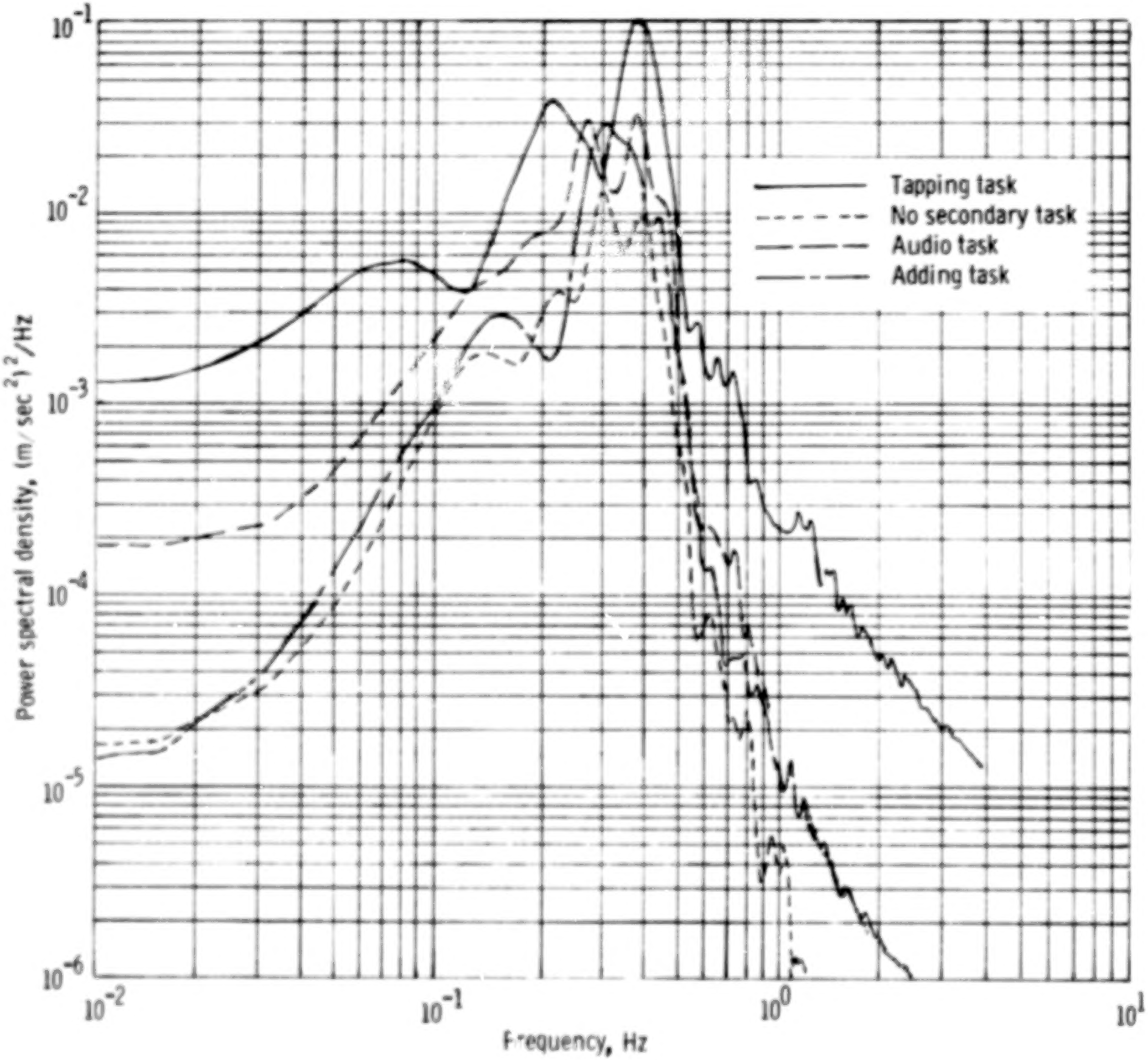

(d) Lateral acceleration a_Y.

Figure 12.- Concluded.

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16. Abstract

An exploratory study has been made to examine the effect of secondary tasks in determining permissible time delays in visual-motion simulation of a pursuit tracking task. This study uses a single subject, a single set of aircraft handling qualities, and a single motion condition in tracking a target aircraft that oscillates sinusoidally in altitude. In addition to the basic simulator delays the results indicate that the permissible time delay is about 250 msec for either a tapping task, an adding task, or an audio task and is approximately 125 msec less than when no secondary task is involved. The magnitudes of the primary task performance measures, however, differ only for the tapping task. A power spectral density analysis basically confirms the results obtained by comparing the root-mean-square performance measures. For all three secondary tasks, the total pilot workload was quite high.

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